BUGWEED, A SHORT FIBRE SOURCE OF HIGH POTENTIAL

By

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Declaration

I, the undersigned hereby declare that the work contained in this thesis is my own original work and has not in its entirety or part been submitted at any university for a degree.

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ABSTRACT

The bulk of paper grades destined for the printing industry are produced on modern paper machines which continuously become wider and faster. In order to improve printability, print quality and dimensional stability, such papers contain a large percentage of mineral pigments either in the form of internal loading or external coatings. Although mineral pigments exercise a substantial beneficial effect on paper surface quality, unfortunately these minerals do not contribute towards sheet strength and machine runnability. Today's papermakers are faced with the dilemma of producing highly filled and coated printing papers with low grammages on faster running paper machines, but often lacking the required quality of fibre resources to secure a smooth runnability of such at high speeds. Standard fibre furnishes will have to be upgraded with special types of reinforcing fibres in order to meet the demands of sheet strength and machine runnability. The investigation had succeeded to identify a new suitable fibre resource, which would satisfy the demand of a reinforcing type natural material.

Opsomming

Die oorgrootte meerderheid tipes papier wat vir die drukkersbedryf bestem is, word op moderne papiermasjiene vervaardig wat steeds breër en vinniger word. Om die drukbaarheid, drukkwaliteit en dimensionele stabiliteit te verbeter, bevat sulke papiere groot hoeveelhede minerale pigmente wat in die vorm van interne ladings of as eksterne bestrykings teenwoordig is. Alhoewel minerale pigmente 'n merkbare voordelige effek op die papier oppervlakte-kwaliteit uittoefen, dra sulke pigmente ongelukkig nie by tot die sterkte en loopvermoë van die papier nie. Die hedendaagse papiervervaardiger word konfronteer met die dilemma om swaar gevuldeen bestrykte drukpapiere met lae oppervlaktegewig op vinniger lopende papiermasjiene te vervaardig. Dit gebeur dikwels sonder die beskikbaarheid van die nodige hoë-kwaliteit veselbronne om te verseker dat die loopvermoë van die papier teen hoë spoed nie benadeel word nie. Standaard veselsamestellings sal opgegradeer moet word met spesiale tipe versterkingsvesels om aan die uitdaging van hoë velsterkte en masjien-loopvermoë te voldoen. Hierdie ondersoek het daarin geslaag om 'n nuwe geskikte veselbron te dentifiseer en wat aandie behoeftes van 'n versterkingsvesel sal voldoen.

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1.1 Introduction

The continually expanding paper industry, with increasing needs for specialized pulps, should certainly be aware of the properties of non-woody plants. Their relative porous structure provides easy penetration by chemicals. Non-woody plants usually have lower lignin and higher hemicelluloses content than most wood species, and they show extremely rapid response to refining. This property is so marked that investigators, accustomed to handling wood pulps are likely to subject annual crop pulps to too rigorous conditions, with the resultant development of undesirably high wetness values of the fibre furnish. This condition is by no means true for all annual crops. In such studies many plants with extremely low pith contents were found[1,2].

In considering annual plants (non-woody) for pulping, one also needs distinguish between monocotyledonous and dicotyledonous plants. These two classes have basic structural differences, which can be quite pertinent in their utilization for pulping. The monocotyledonous plants (which include all the sorghums, sugar cane, bamboos, reeds, grain straw and grasses), are plants having outside rind fibres that are more or less densely packed together enclosing the major cross-sectional area of the plant. They are composed of parenchyma cells through which there are longitudinal fibre vascular bundles or ducts (Fig 1). Although only the bast fibres of such plants as hemp, flax, jute and kenaf have been used for speciality and cordage papers, little effort has been made to produce pulp from the whole stem of these monocotyledons.

All commercial hardwood and softwood species are classified as dicotyledons. This includes herbaceous tree-like plants. The latter occur as shrubs, small trees and creepers.

These fundamentally different characteristics of mono- and dicotyledons will undoubtedly influence the manner in which each plant group is used as a pulping raw material.

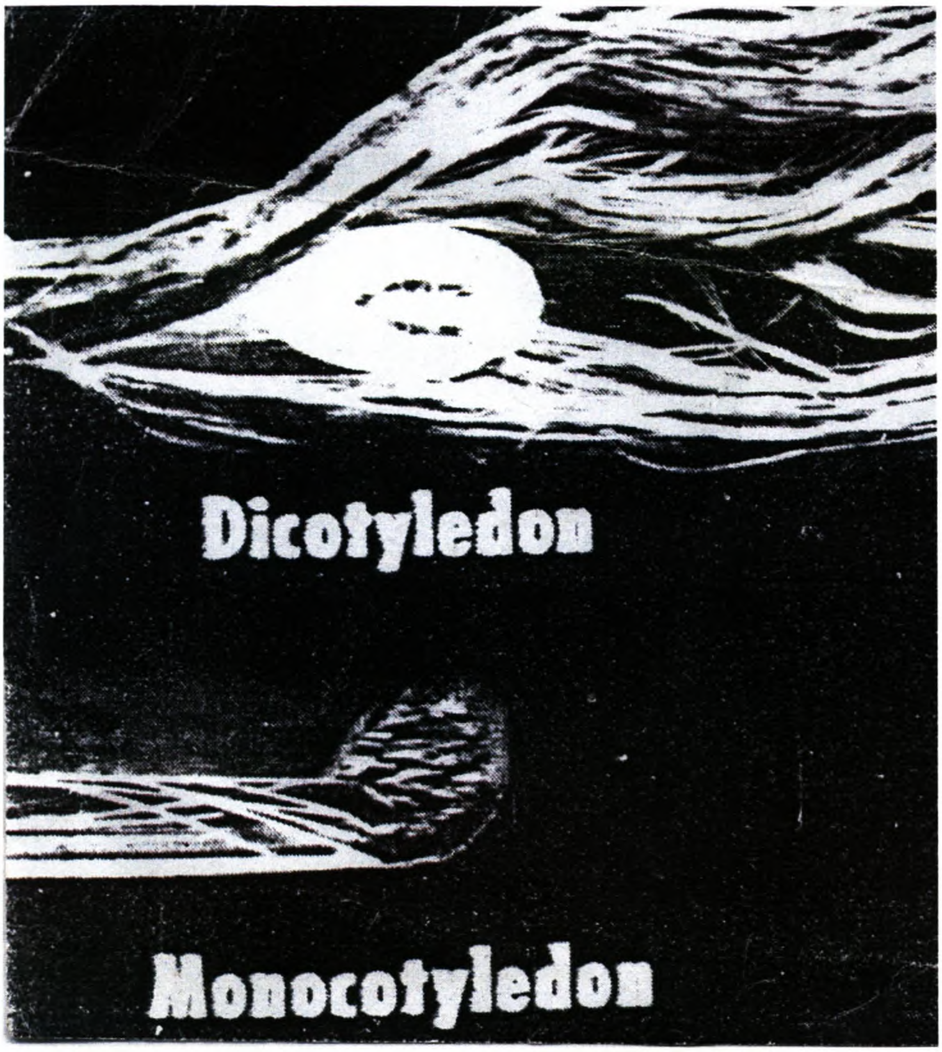

Figure 1: Cross-sectional view of a typical monocotyledon and dicotyledon plant showing distribution of fibre vascular bundles in monocotyledon and bast fibres in the bark of the dicotyledon [3].

Table 1.1 Classification of plants according to their families and genus [4,5].

Monocotyledoneae (Annual plants)		Dicotyledoneae (Perennial plants)	
Family	*Genus*	*Family*	*Genus*
Gramineae	*Oryza, Zea, Triticum, Saccharum, Bamboo Pennisetum, Panicum*	*Pinaceae*	*Pinus, Abies, Picea, Tsuga, Larix*
Tiliaceae	*Corchorus*	*Malvaceae*	*Hibiscus,Cola,Triumfetta, Urena, Malva, Abutilon, Tilia, Bombax*
Agavaceae	*Agave, Yucca*	*Salicaceae*	*Populus, Salix*
Moraceae	*Cannabis*	*Leguminosae*	*Acacia,Crotalaria,Albizia, Mimosa,Senna*
Musaceae	*Musa*	*Solanaceae*	*Solanum, Capsicum*
Linaceae	*Linum*	*Magnoliaceae*	*Magnolia,Ciriodendron*

1.2 Annual and perennial plants

Annual plants are those plants with a life cycle of only a year or less, and most of these plants belong to the mocotyledoneae class as shown in Table 1.1 above. Perennial plants are those plants with a life cycle that lasts more than a year and most of these plants belong to the dicotyledoneae class. From annual plants pulp can be produced from grasses, leaf and bast fibres.

1.2.1 Leaf and Bast fibres

These fibres usually have a low lignin and high cellulose content. Leaf fibres have a higher pentosan content than the bast fibres but lower than cereal straws. For many years the furnish for manufacture of ledger and cigarette paper was linen rags. Seed flax-straw mixtures have supplemented and replaced linen rags for the manufacture of variety of speciality papers including cigarette paper. One of the unique characteristics of leave fibres is their high tear strength. Leaf and bast fibres produce pulps composed of long and more slender fibres and developing higher paper strength[6]. In many countries where there is a shortage of long-fibred pulp supply, leaf and bast fibres are added to increase specific paper properties. Pulp produced from leaf and bast fibres is also blended with short-fibered hardwood pulp and pulp produced from agricultural residue.

Malvaceae: This family is the source of a number of bast fibres used commercially.

Kenaf *(Hibiscus cannabinus)*: It belongs to the *Malvaceae* family. It grows to about 3-4 m high and has a stem diameter of 3-4 cm. It is grown in Southeast Asia, Africa, China, the Caribbean and Southern States of the USA. For some time it has been used as a substitute for *hemp* and *jute* in the manufacture of coarse cordages and fabrics.

In a study project carried out at the University of Georgia, USA, the growing, harvesting, pulping and papermaking properties of *Kenaf* was assessed. It was suggested that the production of *Kenaf* pulp would be commercially viable in Georgia and that *Kenaf* produced pulp with excellent papermaking characteristics[7,8].

Kenaf plant stem may be processed to fibre. The pulping of the whole stem plant was introduced on commercial scale in a continuous chemical pulping operation in Thailand and the resultant pulp was readily bleachable to 85% brightness[12,14].

Legumes *(Leguminosae)* and **Mallow** *(Malvaceae)*: These families were reported to have the most favourable pulp strength properties[3].

Leguminosae: Analyses of 37 legumes were reported [3]. Out of these legumes, *Crotalaria* and *Sesbania* were outstanding in pulp evaluation studies. Both *Crotalaria mucronanta* and *Crotalaria spectabilis* have been grown in the Southern States (USA) as soil improving crops. *Crotalaria striata*, a native of the East Indies, is an erect plant up to 1.5m tall. The characteristics of these and other *Crotalarias* indicate that more extensive exploration of this genus is warranted. The genus *Sesbania* as a pulp fibre source which includes several species with good chemical and physical characteristics coupled with favourable growth habits. This genus includes some 20 species of herbs and shrubs of the tropics and subtropics. *Sesbania drummondii, S. exaltata* and *S. vesicaria* are native to the South Western States (USA). *Sesbania drummondii* is a short-lived perennial, with rapid growth, becoming 2.5 to 4m tall. The other two are annual crops, which attained about the same height as *S. drummondii*. All species of this genus are capable of producing sufficient fibre per hectare to recommend their consideration as a source of raw material for pulping.

Sisal *(Agave sisalana)*: *Sisal* is the fibre that comes from *Agave sisalana*, *Agave cantal* and *Agave fourcroydes*. The most suitable of all *sisal* fibres in terms of strength, colour and cleanness is obtained from *Agave sisalana.*

Sisal is semi-xerophytic. It is well adapted to semi-dry regions, where very few plant species can tolerate such a climate. It is widespread throughout the Southern Hemisphere, from South America, Africa, West Indies and Indonesia [9]. In South Africa commercial *sisal* cultivation extends from KwaZulu Natal to Gauteng, and in the Mpumalanga and Limpopo provinces.

The National Sisal Marketing Board in South Africa is interested in assisting in any possible manner to promote the cultivation of *sisal* [10]. In South Africa, presently *sisal* is only used for the manufacture of ropes and mats. The domestic production of decorticated *sisal* is about 5500 tons per year[10]. The world production of *sisal* pulp is about 30000 tons per year. This level of production cannot sustain a large pulp mill.

Sisal, if readily available, may prove to be an excellent fibre source to be blended with wood fibre.

1.2.2 Grasses

Grasses have been used for papermaking since ancient times. The chemical composition and morphological characteristics of several grass species have established their suitability for papermaking[11]. However the commercial use of individual grass species has seldom been implemented in paper manufacture.

Investigations by Nelson *et. al* [3] showed that among the annual plants, *Gramineae* or the grass family, was of standing promise as a source of annual harvested pulp crops.

Abaca *(Musa textiles Nee)*: In the paper industry, this fibre is mostly used by a group of mills for paper bags for flour, animal-feed sacks, gaskets, sand paper and duplicating papers. It is used in the production of these papers for its excellent coarseness fibre and paper strength development.

The average fibre length of *Abaca* is 4 mm and the cell wall thickness is 16-32 microns.

Bamboo *(Gramineae sub-family Bambusoideae)*: Within this family, the members of the *Bamboo* received the highest overall evaluation as a source of pulp fibre. *Bamboos* fall into two groups, the running *Bamboos* and the clump *Bamboos.* In general the clump *Bamboos* are less cold hardy than the running *Bamboos*, owing to their slow growth in temperate regions. The only clump *Bamboo* that was considered in the studies of Nelson *et al* [3], was *Sinarundinaria murielae*. The running bamboos, which include *Phyllostachys andarundinaria*, were among the new promising sources for paper pulp in the United States where it grows well in the Southeast and along the Pacific coast. It is also used in India. The total number of paper mills in the world that are using *Bamboo* as raw material is forty-four. In India alone there are fifteen paper mills and one in Africa, which is situated in Nigeria. The rest are distributed throughout the world [12].

China jute *(Abutilon theophrasti)* is an annual plant extensively grown in China for its strong, coarse fibres used in paper production.

Elephant grass *(Pennisetum purpureum)*: This species is native to tropical Africa. It is probably the most productive grass under high levels of nitrogen fertilizer addition. *Elephant* grass produces broad leaves on thick, cane-like stems up to 3.5m high, has short stout underground stems, and these spread to form a stool up to one meter across.

It has been used mainly as green fodder for dairy cows, but it is also a favourite grass for cut and carry systems in developing countries [13]. If *Elephant* grass is effectively grazed and slashed occasionally, it can be kept in a dense leafy state, not growing higher than 1.2 meter [13]. Because its seed is of a poor quality in terms of germination, it is propagated vegetatively using stem pieces with four or five nodes per meter square. Unpublished results on the suitability of *Elephant* grass as raw material for fibre production [13] are summarized in Table 1.2 (on page 7).

Table 1.2: Strength properties of handsheets made from *Elephant* grass pulp and refined to 38 ^{0}SR[13].

Age class of raw material	Breaking length (km)	Tear index ($mN.m^2/g$)	Burst index ($kPa.m^2/g$)
2 months	8.4	7.5	2.55
4 months	8.2	8.0	2.50
6 months	7.4	6.7	1.90
1 year	7.5	6.9	1.80

Hemp *(Cannabis sativa)*: It originated from central Asia and has been cultivated in Asia and Europe for many years. *Hemp* was reintroduced in England in 1993 after an absence of 50 years and has been a subject of studies to determine its potential for establishing a sustainable regional pulp industry[14,15].

It has an average fibre length of 22 mm and a fibre width of 16-50 microns. The walls are thick and have knots at intervals. There are two types of *Hemp* that are used for commercial purposes.

i. Bast fibres for *Hemp* yarns and twines

ii. Long bast fibres and short core fibres for fine paper

Hemp fibres are also used to produce speciality grades paper such as cigarette, bible and condenser papers.

Reed Canary Grass *(Phalaris arundnacea L.)*: It is a perennial plant, which is a source of short fibre in the Northern hemisphere [16]. Chemical and morphological properties of *Reed Canary* grass are highly dependent on the plants development stage at time of harvesting as well as the growing site. It gives high yield and excellent pulp characteristics for the production of printing paper [16].

Fibre length of *Reed Canary* is comparable with hardwood fibres, but contains a high amount of fines. *Reed Canary* fibres are coarser than *Eucalyptus* fibres. It contains the same amount of hemicelluloses as hardwood fibre, but has less lignin and cellulose.

Table 1.3: Properties of calendered paper containing different amounts of *Reed Canary* grass and *Birch* pulp [16].

Reed Canary grass content %	Tear index ($mN.m^2/g$)	$Cobb_{60}$	Breaking length (km)	Scott plybond (J/m^2)
0	7.00	21.6	5.04	317
20	6.97	22.5	5.15	341
35	6.92	22.9	4.64	359
50	6.77	23.2	4.62	371
70	6.03	24.3	4.40	416

Sabai *(Eulaliopsis binata Retz)*: Sabai grass is perennial, and grows to a length of about 1m. From the paper point of view Sabai is the most important grass that is found in different parts of India. It has been used since 1870 and approximately 60000 tons of pulp is produced annually[17]. Although Sabai grass has been used for nearly a century for manufacture of writing and printing papers, no systematic work on it has been published [17].

Switch grass *(Panicum virgatum)*: It has a high cellulose, low ash, lignin and extractive contents. The fibre characterization revealed that this pulp is characterized by its large variation in fibre lengths and coarseness[10]. Kraft pulping of *Switch* grass showed that it can easily be pulped to low Kappa numbers with acceptable pulp yields, i.e. 50% total yield at Kappa number 14[11]. Burst, tear, tensile strengths and wetness properties are typical to that of nonwood fibres.

1.3 Agricultural residues

Residues from agricultural crops such as sugar cane, rice straw, wheat straw and others have been extensively used in the pulping industry.

Bagasse *(Saccharum):* This is the residue from the sugar cane industry. It has been considered as a source of fibre raw material for a number of years in India[18,19], Latin America[20], Cuba [21], Thailand [22] and in African countries such as Egypt and South

Africa [23]. In India, only 5-6% of *Bagasse* is available for pulp production, the rest is used as a fuel by the sugar refining companies. In 1994 there were about 87 *Bagasse* paper mills of around the world [12]. In South Africa *Baggase* is being successfully used for fine paper and tissue manufacture at SAPPI Fine Papers Stanger [12], KwaZulu Natal.

Bagasse fibres have pointed ends and are thin to thick walled with no characteristic markings of the cell wall, except for the presence of occasional simple pits. The fibre length is about 1.7mm long. There are also vessel segments, which range in length up to 1.3mm.

***Cereal straws**:* The straws of rice, barley, wheat and oats have been pulped in different parts of the world since the early part of the 19th century. There are two kinds of straw pulp:

i. Unbleached pulp which is used in manufacturing of paper cores, egg cartons, straw board and fluting paper.

ii. Bleached straw pulp which is used in fine papermaking

In South Africa SAPPI (Enstra) was the first to use cereal straws for pulping[23].

***Flax** (Linum usitatissimum)*: *Linum* is a genus of nearly 200 species spread over the temperate and warm temperate zones of the Northern Hemisphere, most commonly occurring in Europe and Asia but with about 50 species also being cultivated in South America [25].

It is an annual, self-fertilizing plant grown for its highly quality fibre (*Flax* fibre) or its seed (oil *Flax*, seed *Flax*) or for both (dual purpose *Flax*). *Flax* varieties producing fibres are up to 120cm tall, scarcely branched and are grown in the more temperate regions through the Northern Hemisphere, especially in the former USSR. Its average fibre length is 25mm. The fibres have thick cell walls with nodes occurring at regular intervals. *Flax* fibres are stronger than those of cotton or wool.

***Maize** (Zea mays)*: Most of the maize stalk is consumed directly as feed for livestock. USA is one of the chief maize producing regions, which produces half of the world's total production[24]. The other chief maize producing regions are USSR, Romania, Yugoslavia, Hungary, Italy, China, Brazil, Mexico, Argentina and South Africa.

Some investigations of chemical properties of maize leaves were carried out at Stellenbosch University and results are shown in Table 1.4 below. Maize was found to have good pulp yield (49%) but its handsheets were not tested[24].

Table 1.4: Chemical properties of maize[27].

% Extractives	% Lignin content	% Holocellulose
5.00	23.29	34.18

1.4 South African intruder plants with a possible fibre potential.

Black Wattle *(Acacia mearnsii)*: It occurs naturally in South-Western Australia. Its range includes New South Wales, Southern Queensland, Tasmania, Victoria and the South Eastern areas of South Australia. It thrives in soils derived from sandstone, granite and dolerite. Its fibre properties are shown in Table 1.5 (on page 16).

In 1864 van der Plank (a farmer of the Camperdown area in Natal) introduced *Black Wattle* in South Africa [25]. Initially the plant was introduced to be grown as a source of firewood and wind shelter, but by 1880 it has been cultivated in commercial plantations for its bark. In 1886 the first tannin bark was exported to Britain. The species is now also cultivated extensively in India, Japan, Kenya, Tanzania, Uganda, Brazil, Uruguay and Argentina.

Black Wattle is now considered to be a widespread invader plant in South Africa particularly along rivers streams and ditches. In the Cape it has spread along roads and rivers and extends from the Cedarberg to the former Transkei region. It grows well in high rainfall areas on deep, well-drained soils but also establishes itself on shallower soil if there is sufficient water [25].

In many areas where it occurs, excluding commercial plantations, it forms dense impenetrable jungle thickets, which suppress the indigenous vegetation, and along water courses impedes the water flow [25].

The grubbing of plants and severing below the junction of roots and stems is recommended and does not need chemical control. Cut stems above the ground should be treated with 2,4,5-T in diesel oil. Ring barking is a very successful method for killing large trees [25].

Blackwood (*Acacia melanoxylon)*: *Blackwood* is a plant native to Australia and is found in Tasmania, South Australia, Victoria, New South Wales and South-Eastern Queensland. Worldwide, this tree is one of the most important Australian *Acacias* for furniture making and cabinet construction. In South Africa it also has become an invader of indigenous vegetation. It was introduced to the Cape in 1856. It was used extensively from 1856 as a forest replacement species in the Knysna forest, where it was planted in the gaps created by the felling of indigenous giants such as Yello-wood and Black Stinkwood. Its fibre properties have not been reported yet.

Blackwood is an erect, evergreen, unbranched tree from 10-35m tall, with clean bole and dense crown

The distribution of the *Blackwood* in South Africa is from Cedarberg mountains to the Cape Peninsula, eastwards along the coast through Knysna and the Eastern Cape into KwaZulu Natal and northwards to part of the Transvaal. It grows best in moist and cool situations and is most common in forests, on forest margins and along streams.

In forests, *Blackwood* is quick growing. The seeds with reddish seed-stalks are relished by various birds, which act as an effective dispersal agent. These seeds have a tough, hard skin and very resistant to predation and decay. The seeds lie dormant in the soil for many decades before germination takes place. It is thus possible for large stores of seed to be building up in the soil surrounding the tree.

It is difficult to control because the plant is capable of rapid vigorous regrowth from root suckers and regeneration from seed. The control strategies available are the eradication of the tree and saplings, preferably before seed production, and seed destruction using some form of biological control.

Figure 2: Young tree of Bugweed

Bugweed *(Solanum mauritianum)*: *Bugweed* is not indigenous to South Africa, but originates from Southern America. It is a perennial forming a bush or small tree up to 6m in height. At the young stage the stems are covered with greyish-white hairs, but become smooth later. Leaves are arranged alternately and reach a size of up to 300mm in length and 150mm in width. Flowers are purple and arranged in dense terminal open –flowered groups. Its fibre properties are shown in Table 1.5 (on page 16).

Bugweed has established itself extremely well in the Central and Eastern parts of South Africa. It quickly colonises disturbed areas, farmlands, open spaces along roads, in Pine forests and generally everywhere where a major disturbance of the soil has occurred. This weed overgrows the planted tree species in plantations and therefore competes for light and available water. The growth reduction on plantation species, as caused by this competition is not precisely known[26]. Birds tend to spread the seed and the plants quickly invade plantation areas, which makes control very difficult.

Cluster pine *(Pinus pinaster)*: The average fibre length of *Cluster pine* is 2.77mm. Its fibre properties are also discussed in Table 1.5. *Cluster pine* occurs naturally in the

Mediterranean region of Europe, from the Adriatic Sea in the east to the Atlantic coast of France, in major parts of the Iberian Peninsula, on certain Mediterranean islands and in parts of North Africa. The French Huguenots introduced it to South Africa. A plantation was established at Genadendal in 1825 and the species has since been used for plantation afforestation on poorer sites. It is commercially planted in the Western Cape and Southern Cape provinces.

Cluster pine has become naturalized in Southern African regions that receive winter and year round rainfall, and where the rainfall exceeds about 500mm per year.

Trees bear seeds from about the sixth year onwards. Germination and establishment is rapid especially after veld fires. Stream flow from catchments infested with *Cluster pine* is usually reduced, grazing is lost, accumulation of heavy fuel increases the hazard of blown up fires and natural veld is overtopped and ultimately suppressed. Baboons and birds also spread this intruder tree, by eating its seeds and scattering them in mountainous area where they germinate.

Much of the land invaded by *Cluster pine* is state-owned and the Department of Water Affairs and Forestry is responsible for its control [25]. At present, mechanical removal is the most effective method of control. Pines are felled by cutting at ground level and the veld is burnt under control from twelve to twenty-four months after the felling operation, in order to destroy seedlings.

Mesquite(** *Prosposis glandulosa):** *Prosposis* is a woody tree native to North-Eastern Mexico and South-Western U.S.A. It is a spiny, thicket-forming shrub or tree growing up to 10m high and is very variable in leaf shape, size and number. The tree occurs naturally in valleys and dry uplands but rapidly invades abandoned land, commonages, fence rows, established pastures, and overgrazed veld. It is cultivated in South America, Africa and Asia as an ornamental and as a fodder tree [25]. Its fibre properties are also summarized in Table 1.5.

Prosposis grows in the drier regions of the central North Western Cape, in the Kleinbegin, Carnarvon, Vanwyksvlei, Pofadder and Kimberley areas. It is also widely grown as an ornamental in much of the Western Cape and as far as Bredasdorp. It has become established in the Karoo and Kalahari Thornveld.

Since *Mesquite* is well adapted to withstand severe drought, it survives in many areas where it can rapidly dominate the less robust indigenous vegetation. The distribution area of this plant is therefore far in excess of the area already infested. This plant produces a number of seeds in edible pods. The pods are often eaten by wild and domestic animals and because seeds can pass through an animal's digestive tract unharmed, it is effectively dispersed over a wider area. Seed may lie dormant in soil for up to 10 years but germinate readily in dung. One of the biggest dangers posed by *Prosposis* is its rapid response to inefficient control.

The most common employed methods of mechanical control are root ploughing, chain pulling, hand and power grubbing. Chemical control is best undertaken during the peak growing periods of the plant, usually between August and October. Type of chemical used and the method of application depend very much on density of infestation. A combination of chemical followed by mechanical control can be very effective. There are no chemicals that are registered in South Africa for use against *Mesquite* [25].

Poplar *(Populus canescens)*: This specie originates from Central and Northern France and the British Isles. It was introduced in South Africa in the 1920's from Eurasia as anti-erosion agent and for the production of matchwood. It threatens indigenous plant communities, invades river banks and dongas, forming dense bush.

Port Jackson *(Acacia saligna)*: It is native to South Western Australia, which extends from the Murchison River north of Geraldton to Mount Ragged, east of Esperance. It is now naturalized in parts of New South Wales. It was introduced in South Africa in 1833 for binding the sandy soil in a dune reclamation programme. Its fibre properties are not yet reported. Its paper properties are shown in Table 1.5 (on page 16).

Port Jackson has an open willowy appearance and grows up to 9m in length. It is confined mainly to the coastal plain in areas of a mean annual rainfall greater than 250mm. It occurs commonly from the Olifants River in the South Western Cape, to as far at the Great Kei River in the Eastern Cape. But as in Australia, this *Acacia* has also extended inland. Recent findings[25], show that *Port Jackson* is establishing itself both in the dry, lower regions of the Orange River and in the wetter parts of the Southern Transkei region. The principal dispersal agents of seeds of *Port Jackson* are man and water.

Port Jackson grows rapidly after fires and sprouts profusely when the trunks are severed. This makes them difficult plants to clear off land needed for agriculture. Bad agricultural practices which disturb the indigenous vegetation growing on sandy soil will promote the spread of *Port Jackson*[25].

Particular care must be taken when eradicating port Jackson to ensure that the plants are either removed entirely or that the stumps are treated with chemicals.

Although certain chemicals are being used to control this species, these chemicals cannot be recommended, as they are not yet registered for use against the plant.

Stinkbean (*Albizia laphantha)*: *Stinkbean* is plant native to Western and South Western Australia, which has become naturalized in Eastern Australia. It was among the first plant invaders to be introduced from Australia into South Africa. Earliest records show that Baron von Ludwig introduced *stinkbean* to his garden in 1833. Its fibre properties are not yet reported[25].

Stinkbean is an evergreen shrub or small tree usually about 4-6 m high but which can reach 15 m under favourable conditions.

Stinkbean is common along the Liesbeek River in the Western Cape Province. It shows clear signs of becoming an invader of indigenous vegetation particularly in kloofs, on moist slopes and along stream banks. At present its occurrence extends all along the coastal belt from the Cape Peninsula to as far as Stutterheim and as far as the Fort Beaufort area. It can be contained, or preferably eradicated, by such manual means as chopping down large trees as close to the ground as possible, or by grubbing out saplings by their roots and by pulling up seedlings by hand. This species does not resprout after fire or felling. There is no chemical registered for the control of stinkbean. Fibre properties of this species are not reported yet.

River reed *(Phragmites australis)*: There is not much reported on this species relating to its fibre properties. Its paper properties are shown in Table 1.5 (on page 16).

The Department of Wood Science at University of Stellenbosch has carried on some research in pulping some of these intruder pants. These results are summarized in Table (1.5 on page 16).

Table 1.5 Summary of Pulp Evaluation Results of Intruder Trees Species carried out at the Department of Wood Science, University of Stellenbosch [29,30].

Species	Beating time (min)	Wetness ^0SR	Breaking length (km)	Tear Index ($mN.m^2/g$)	Burst Index ($kPa.m^2/g$)
Acacia mearnsii (Black Wattle)	0	19	3.26	6.41	1.72
	1.5	26	6.12	7.44	4.04
	3	41	7.76	9.03	5.89
	4	54	9.30	8.51	6.65
Prosposis glandulosa (Prosopis)	0	18	1.52	1.97	0.27
	1.5	24	3.19	3.06	0.63
	3.5	33	5.19	4.69	1.25
	5.5	46	6.05	6.68	1.54
Phragmites australis (River reed)	0	37	7.96	8.45	2.33
	4	43	9.02	9.38	2.81
	8	48	10.04	9.02	3.63
Pinus pinaster (Cluster pine)	0	10	1.54	17.07	3.36
	7	18	2.99	19.53	5.34
	12	30	5.30	20.88	5.80
	19	41	6.30	19.79	7.32
Solanum mauritianum Western Cape Bugweed	0	25	0.84	3.40	5.67
	1	33	1.70	5.15	9.48
	2	44	2.64	5.97	12.55
	3	54	3.21	7.37	14.90

Table 1.5 continuation

Species	Beating time (min)	Wetness ^{0}SR	Breaking length (km)	Tear Index ($mN.m^2/g$)	Burst Index ($kPa.m^2/g$)
Solanum mauritianum Highveld Bugweed	0	23	1.12	4.03	6.68
	1	32	2.78	6.77	11.26
	2	40	3.95	8.10	13.83
	3	50	5.63	7.88	18.23
Solanum mauritianum Lowveld Bugweed	0	19	0.66	2.66	3.52
	1	32	1.48	5.69	7.90
	2	41	2.64	6.74	10.22
	3	50	3.59	7.93	14.83

Table 1.6 Summary of Pulp Evaluation Results of some Agricultural Residues and Non-woody Plant Species[31,32,33] .

Species	Type of pulp	Freeness (CSF)	Burst index ($kPam^2/g$)	Tear index (mNm^2/g)	Tensile index (Nm/g)
Sisal	Unbleached	400	5.80	19.4	0.49
	Bleached	400	4.60	19.0	0.49
Abaca	Unbleached	250	9.60	24.0	10.39
	Bleached	250	10.40	27.5	10.98
Flax	Unbleached	250	2.40	24.5	3.14
	Bleached	250	2.30	23.5	3.24
Hemp	Unbleached	147	4.90	6.7	11.57
	Bleached	162	2.10	19.6	3.53
Bamboo	Unbleached				
	Bleached	400	2.60	7.6	4.8
Bagasse	Unbleached	*	1.83	1.26	0.39
	Bleached	282	2.50	4.30	
Jute	Unbleached	*	4.80	3.90	4.8
	Bleached	*	*	*	*

Chapter 2: Project Proposal.

2.1 Background

Through the Community Forestry University Research Network, the Pulp and Paper Section at Stellenbosch became involved in a feasibility study for small-scale paper production using alien species and intruder plants. In this investigation the feasibility of utilizing alien plant material as a possible source of fibre was investigated. During the investigation the potential of Bugweed as an extremely high quality fibre source, was identified. The potential of Bugweed for production of papermaking fibres with demanding qualities, was soon realized. This preliminary investigations indicated that Bugweed produced chemical pulp of high quality short fibre with an amazing strength potential development.

2.2 Objective

Evaluation of the pulping properties, fibre quality and paper properties of Bugweed (*Solanum mauritianum*) from different growth regions in South Africa.

Chapter 3: Experimental

3.1 Experimental layout (sequence of evaluation)

Micro pulping of Bugweed from different regions to evaluate and compare the pulp yield and alkali consumption rate.

↓

Pulp strength evaluation of micro pulping material to select the Bugweed with highest and lowest strength development. All pulp samples to be beaten in a Lampen mill at 30000 revolutions.

↓

Micro pulping of Bugweed with highest and lowest strength values for beating in Lampen mill at different revolutions. Handsheet pulp evaluation.

↓

Macro pulping of Bugweed with highest Lampen mill strength development using

1.Soda AQ method

2.Kraft pulping

↓

Pulp evaluation of Soda AQ and Kraft pulp with Voith overhead beating facility.

↓

Selection of best macro-pulping option to produce sufficient pulp for a pilot paper machine trial and evaluation of strength of machine made paper.

3.2. Origin of raw material

Logs of about 4 to 5m long of *Solanum mauritianum* were obtained from KwaZulu Natal, Mpumalanga Highveld, Mpumalanga Lowveld, Western Cape and Eastern Cape areas. For the purpose of control and comparison *E.grandis* was used and its logs were obtained from KwaZulu Natal region.

3.3. Debarking, chipping and screening

All logs were debarked by hand and chipped in a Wigger pilot size chipper containing four blades and adjusted to produce approximately 20mm long and 8mm thick chips. The chips were screened and all under and oversize material was rejected. Its moisture content was determined before the chips were used for pulping.

3.4. Chemical analysis

3.4.1. Alcohol / benzene and water extractives

TAPPI T264 om-84[34]

3.4.2. Determination of lignin content

TAPPI T222 om-88[34]

3.3.3. Determination of holocellulose

Seifert method[35]

3.4.4. Ash content

TAPPI T15 OS-75[34]

3.5. Physical properties

3.5.1. Determination of chip density

TAPPI Standard T 258 os-76[34]

3.5.2. Fibre length and curvature factor

Maceration was achieved by mixing of 10 cm^3 acetic acid and 10cm^3 hydrogen peroxide in a test tube. Small pieces of the wood material were placed in the test tube, covered with the solution and retained at 60 ^0C for seventy-two hours. The resulting macerated fibres were washed with water. The fibrous material was stained with karminazurol and permanent slides were prepared for projection using alight microscope. A Kontron image analyser was used to measure fibre length and curvature of the projected fibres using a digitiser. A total of 201 fibres in each slide were measured and average fibre length was recorded.

3.5.3 Anatomical features of Bugweed from Highveld and Lowveld

Transverse microtome cross sections of wood samples from Highveld Bugweed and Lowveld Bugweed were prepared. The sections were about 17 microns in thickness and were stained with safranin. The stained sections were permanently mounted on glass slide with entellan. Image analysis was used to measure cell wall thickness, diameter of the cell lumen, number of vessels per surface area, as well as vessel diameter of earlywood and latewood cells using the same magnification.

3.6. Pulping properties of Bugweed

Three types of pulping i.e micro pulping using Soda AQ, macro pulping using Soda AQ and Kraft pulping were used to pulp Bugweed and *E.grandis.* Micro pulping was used to establish the optimum pulping conditions with regards to active alkali consumption (AA), pulping temperature and time for digesting.

3.6.1 Soda Anthraquinone (AQ) Micro pulping of Bugweed from different growth regions.

The micro bombs could accommodate 80g of oven-dry wood chips were uesd. The filled bombs were placed in a digester of 15 *l* capacity, which was half filled with Malotherm heating oil. Six micro bombs could be placed in the digester and submersed in the heating oil at a time. The heating oil was stirred continuously so as to maintain constant temperature. The temperature was monitored with a thermocouple. Different AA additions were used. The conditions of Soda AQ micro pulping of *Solanum mauritianum* collected from the different growing regions and *E.grandis* were as follows:

AA concentrations (charge)	14%, 15%, 16% (measured as Na_2O)
Liquor to solid ratio	4.5: 1
Max temperature	170 ^{0}C
AQ concentration (charge)	1% on oven-dry mass of wood
Sample withdrawal at	50, 100, 130 and 160 minutes (after the digester temperature reached 100 ^{0}C)

The digested material was washed through a 10 mesh screen to separate rejects from the fibres and the accepted pulp was collected on a 100 mesh screen and then spin dried to a consistency of ±30%. The total mass of oven-dry pulp was determined and the screened yield was expressed as the percentage oven-dry pulp in grams divided by the initial oven-dry mass of chips.

Pulp yield (%) = [oven-dry mass of pulp x 100%] / initial oven dry mass of chips...............(1)

3.6.2 Soda AQ macro pulping

Soda AQ macro pulping conditions for the *Solanum mauritianum* (Bugweed) from the Highveld and *E.grandis* were as follows:

AQ	1%	
Active alkali	15% (measured as Na_2O)	
Liquid to solid ratio	4.5: 1	
Cooking time at maximum temperature		170 ^0C
Time at maximum temperature	25 minutes	
Max. pressure in digester at 170 ^0C	800 kPa	

The accepted chips were cooked in a digester of 15 litre capacity, which could accommodate an equivalent of 1500g of oven dry-wood chips. During the cooking cycle, the digester oscillated through 45 degrees to either side to ensure proper liquid contact with the wood chips. The temperature and pressure were monitored with the aid of a thermocouple and a pressure gauge fitted to the lid of the digester. A programmable logic computer (PLC) was used to control the entire pulping cycle. At set intervals the pressure was released with the aid of a solenoid valve, which was controlled by the PLC. The cooked material was washed through a 10 mesh screen to separate fibres from rejects and acceptable pulp was collected on a 100 mesh screen and then spin-dried to a consistency of approximately 30%. The screened yield of oven dry pulp was determined and yield was expressed as percentage oven-dry pulp over initial oven dry mass (refer to equation 1).

3.6.3. Kraft macro pulping

Bugweed from the Highveld and *E.grandis* chips were also pulped in the laboratory using the standard pulping conditions for hardwood.

3.6.4 Kappa number determination

The Kappa number is a measure of the ability of pulp to reduce potassium permanganate under acidic conditions. It is an indirect measure of the lignin content of pulp. Kappa numbers were determined for macro-cooks according to TAPPI standard method T236 CM-85[34]. The experiment was repeated three times for each pulp. The kappa numbers for the micro-cooks were not determined.

3.6.5 Black liquor analysis

25ml of black liquor was sampled into a 500ml volumetric flask. 50ml of a 10% aquous barium chloride solution was added and the flask was filled to the mark with distilled water. The solution was mixed well and left over night. 100ml of solution was pipetted into an Erlenmeyer flask and 5ml of neutral formaldehyde was added. This solution was titrated with 0.1M HCl to a pH of 8.3 using a pH meter. The volume of HCl consumed was used to calculate the residual active alkali as a percentage of mass of alkali consumed.

3.6.6. Shive content

The shive content was obtained by screening the pulp in a Packer slotted laboratory screen. The shives collected were placed in an oven at 105 ^{0}C for 24 hours and weighed. Shive content was then determined as a percentage of original dry mass of wood chips. Shive content was expressed as a % of total mass of pulp.

3.7. Pulp evaluation

Being restricted by the quantitative availability of the pulp obtained from the micro-digesting studies, pulp evaluations of the different fibrous raw materials could only be performed using a Lampen mill, which only could handle small pulp samples. It was decided to perform all the initial evaluations at 30000 revolutions. Following this procedure it would thus be possible to select the Bugweed material producing the lowest and the highest beaten handsheet strength values. The two thus selected Bugweed pulp samples together with the control were then subjected to a full Lampen mill beating cycle to determine the handsheet strength development.

3.7.1. Beating and handsheet formation

The washed pulp was separated from shives before beating. The handsheet strength development i.e. tensile, tear and burst strength of the micro pulped fibre was evaluated by beating in a Lampen mill at 3.5% consistency at 30000 revolutions. The unbeaten and beaten pulp was used to prepare handsheets in a rectangular sheet former according to TAPPI standard method T205 OM-88[34]. Each sheet was dried between two sheets of blotting paper on a photographic plate drier. The pulp obtained from macro-pulping was beaten with a Voith overhead beater at 3.5% consistency. During beating ,aliquots of one litre pulp were removed from the beater at one minute intervals. The same procedure of handsheets making and drying was followed as described.

3.8 Strength testing

All handsheets were conditioned for 48 hours at 65% relative humidity and 20 ^{0}C before being tested. The handsheet were cut to accurately dimensioned test samples with the aid of a die-cutter. The following strength properties were evaluated to each of ten handsheets according to TAPPI standards.

Tensile strength	TAPPI standard T 404 om-87[34]
Burst strength	TAPPI standard T 403 om-91[34]
Tear strength	TAPPI standard T 414 om-88[34]

3.9 Paper machine made paper

800g Soda AQ pulp of *E.grandis* and Bugweed were beaten to 38 ^{0}SR before paper was made with a Fourdrinier machine. The same amount of Bugweed pulp was not beaten and was used to make paper with the machine whilst that of *E.grandis* was beaten for 30 seconds.

Chapter 4: Results and Discussion

4.1 Density and fibre length determination

The chip density results, the fibre length and curvature measurements of macerated material are listed in Table 4.1. For both density and fibre length *E.grandis* is superior to Bugweed. For curvature factor Western Cape and Highveld Bugweed have the highest factor. Bugweed from the Western Cape had the lowest density whilst KZN Bugweed recorded the shortest fibre length. The Highveld and the Lowveld Bugweed recorded the highest fibre length and density as compared to the Bugweeds from the other regions.

Table 4.1: Wood densities and fibre length of Bugweed from different regions compared with *E.grandis.*

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Density $g.cm^{-3}$	0.343	0.291	0.304	0.344	0.322	0.398
Fibre length mm	0.86	0.94	0.96	0.96	0.92	1.12
Fibre curvature factor	1.02	1.03	1.02	1.03	1.00	1.00

4.2. Anatomical features of Highveld and Lowveld Bugweed.

The results of some anatomical characteristics of *E.grandis*, Highveld and Lowveld Bugweed are given in Table 4.2. It appears that the Highveld Bugweed had the largest vessel diameter (average of short and long axes of vessel), followed by *E.grandis*. In terms of cell wall thickness, the latewood cells of tracheid have thicker walls than the earlywood cells of tracheid but the number of vessels occurring in the latewood are fewer in Highveld and Lowveld Bugweed. Highveld Bugweed had highest cell lumen diameter followed by Lowveld Bugweed in both early and latewood cells compared to *E.grandis*.

Table 4.2: Some anatomical features of Highveld and Lowveld Bugweed compared to *E.grandis*.

	Earlywood Highveld *Bugweed*	Latewood Highveld *Bugweed*	Earlywood Lowveld *Bugweed*	Latewood Lowveld *Bugweed*	Earlywood *E.grandis*	Latewood *E.grandis*
Cell wall thickness of tracheid (microns)	3.41	4.52	2.89	3.10	3.21	3.67
Number of vessels per area of 100 mm^2	31	4	370	42	338	34
Diameter of vessels (microns)	239	142	92	89	100	196
Diameter of cell lumen of tracheids (microns)	28.83	10.48	10.48	6.33	6.72	3.15

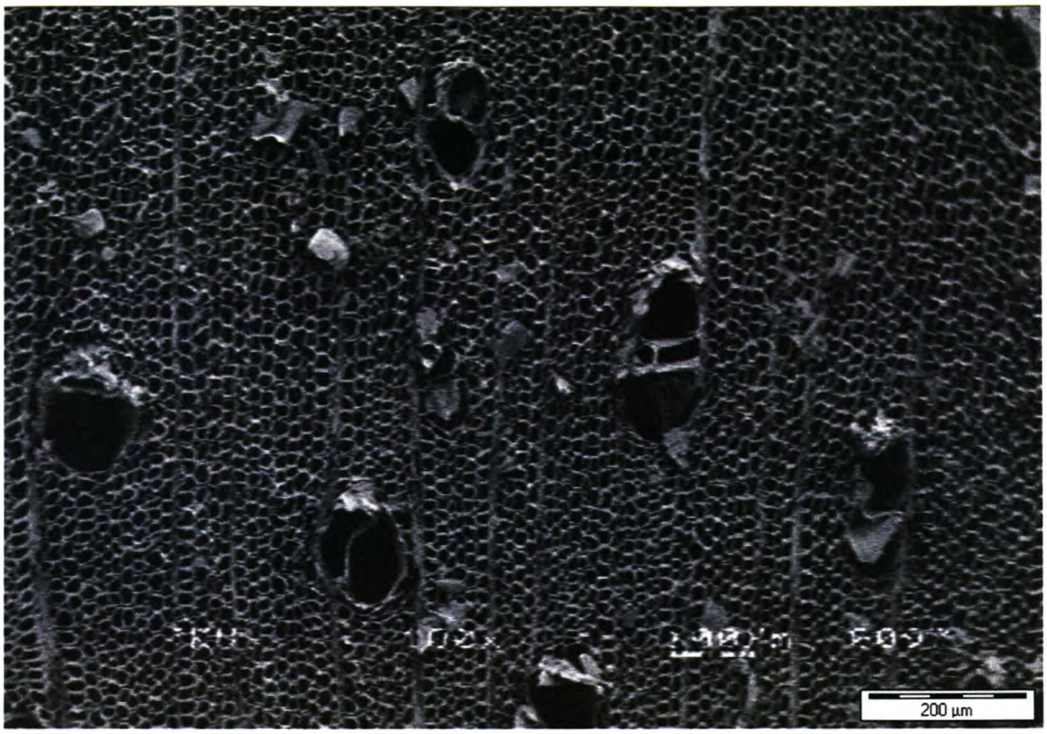

Figure 3: Cross section of Highveld Bugweed showing tracheids and vessels. Magnification: 100x.

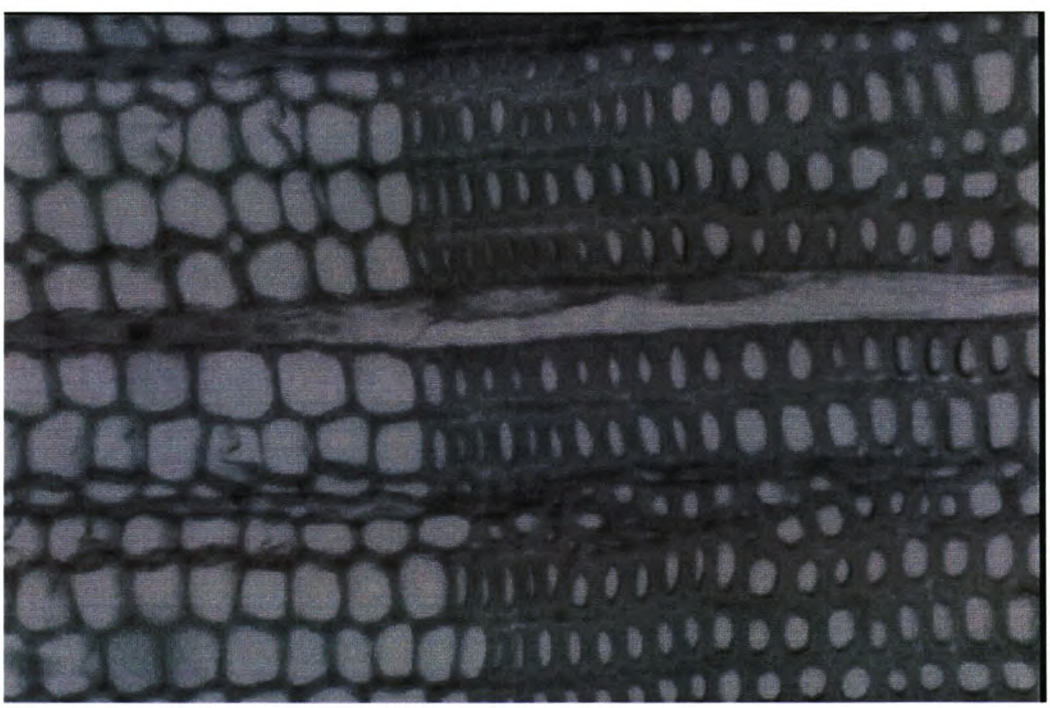

Figure 4: Cross section of Highveld Bugweed showing transition area between latewood and earlywood. Magnification: 400x

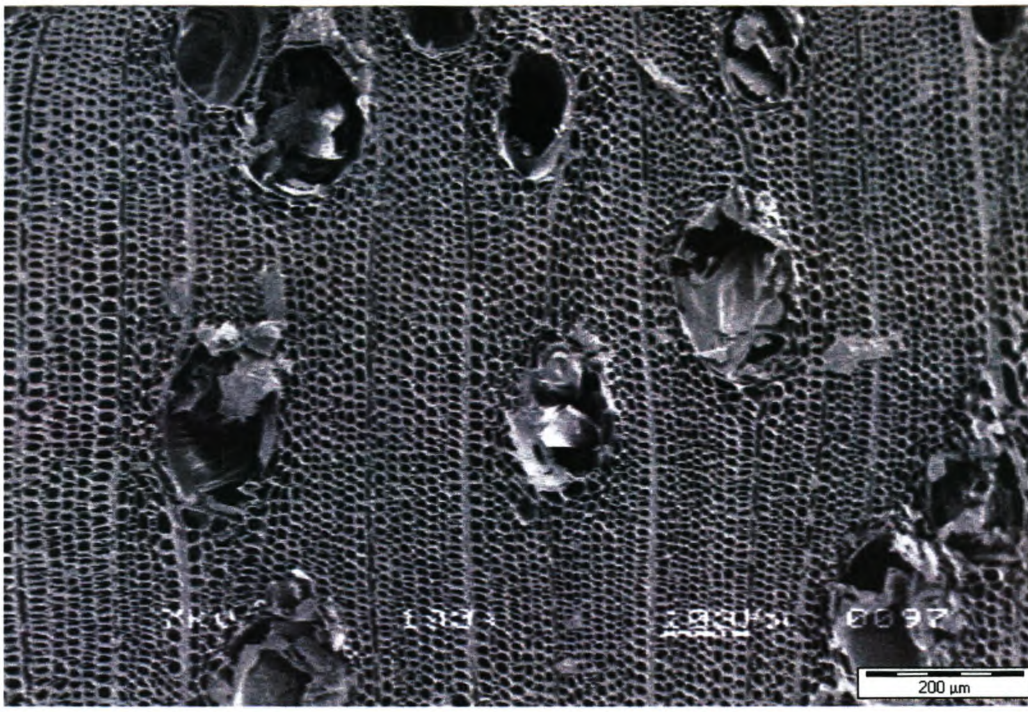

Figure 5: Cross section of *E. grandis* showing tracheids and vessels. Magnification 100x.

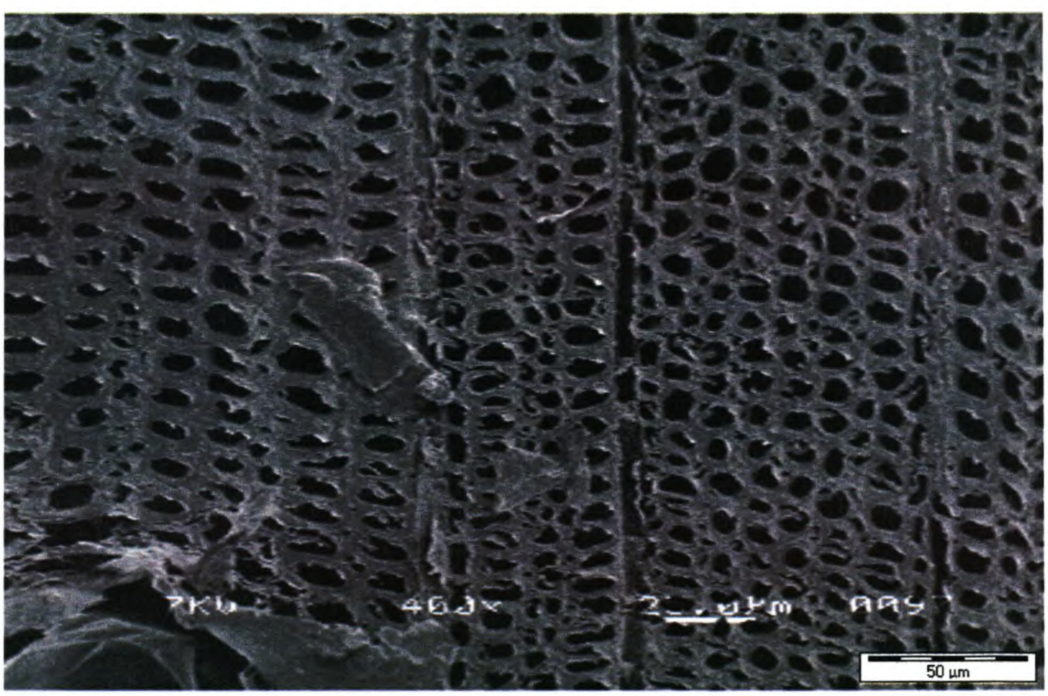

Figure 6: Cross section of *E.grandis* showing tracheids. Magnification: 400x

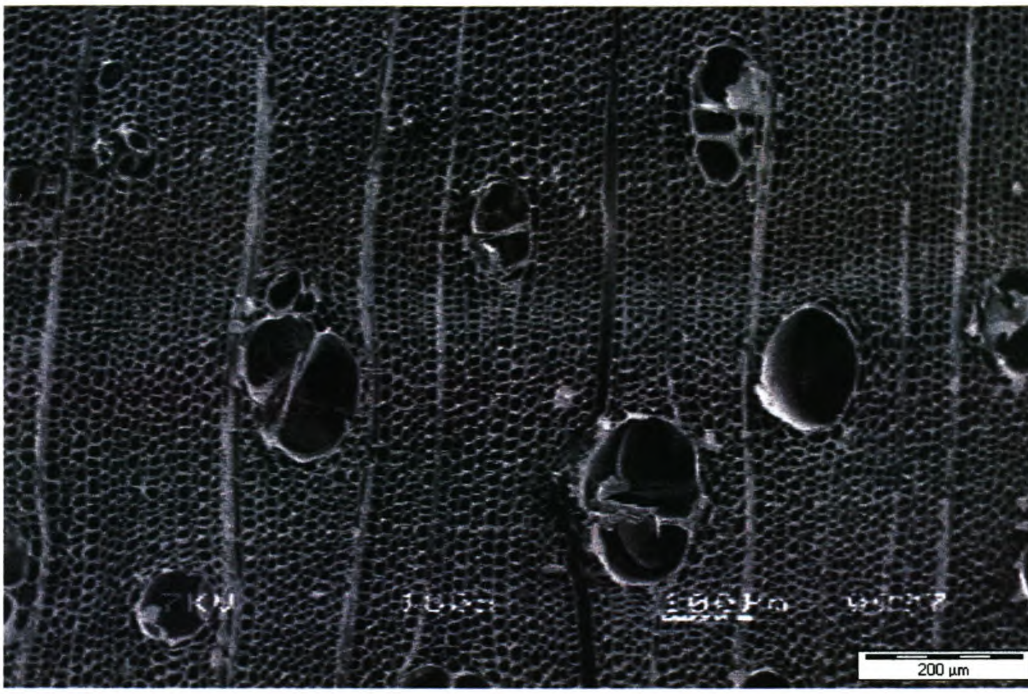

Figure 7: Cross section of Lowveld Bugweed showing tracheids and vessels. Magnification 100x.

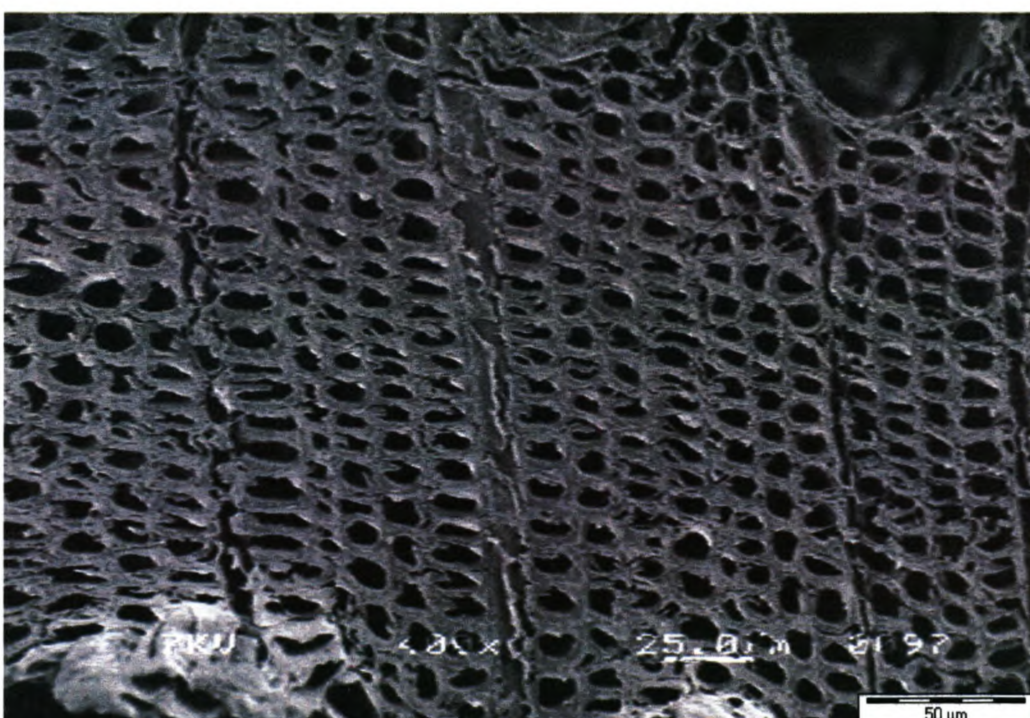

Figure 8: Cross section of Lowveld Bugweed showing tracheids. Magnification 400x

4.3 Chemical analysis of Bugweed and *E.grandis* wood

The results are given in Table 4.3. Ash content, alcohol/benzene and water soluble extractives, and Klason lignin are expressed as percentages of oven-dry mass of wood. *E.grandis* had a lower ash content than any of the listed Bugweeds. It is noticeable that Bugweed had a lignin content around 30%, which was close to that of softwoods. These values were slightly higher than those of Bugweed reported by Rypstra[36]. The lignin content for *E.grandis* coincided very closely with the results obtained by Burger[37]. The Seiffert cellulose determination did not show any significant differences between the Bugweeds of various origins and also did not differ significantly from that of *E.grandis*. It is also noticeable that KZN Bugweed had the highest water solubles whilst *E.grandis* had highest alcohol/benzene extractives.

Table 4.3: Chemical analysis of Bugweed wood expressed as percentage of oven dry mass of wood, compared to *E.grandis.*

	Solanum mauritianum					
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	*E.grandis*
H_2O solubles %	2.8	1.7	1.1	1.2	1.4	2.7
Alcohol / benzene solubles %	1.7	1.7	1.4	1.2	1.9	2.1
Klason Lignin content %	29	30	28	31	30	25
Ash content %	0.5	0.5	0.5	0.6	0.6	0.3
Seiffert cellulose content %	47.4	48.1	48.7	49.6	48.6	48.4

4.4 Micro pulping of Bugweed

4.4.1 Screened Pulp Yield

Results of screened pulp yield (expressed as a % of the oven dry mass of wood) for micro bomb digestion using different AA levels for five different Bugweed materials and *E.grandis,* are shown in Tables 4.4-4.9 and Figures 9-14. Eastern Cape Bugweed produced the highest pulp yield than all other Bugweeds from other regions after 100 minutes cooking time and when 16% AA charge was used (Table 4.8 page 39). From

Figure 9-14 it is noticeable that all raw materials reached maximum yield when 16% and 15% AA charge was used. Maximum pulp yield was not reached after 160 minutes digesting time with the lowest AA addition for all the Bugweed material from the different regions and *E.grandis*. With an application of 15% AA, the pulp yield reached an maximum level after 100 minutes cooking time for the Highveld and E.Cape Bugweeds, whilst W.Cape and *E.grandis* only achieved optimum after 130 minutes cooking time. KZN and Lowveld Bugweed reached optimum pulp yield after 100 minutes when 16% AA was applied. With 16%AA addition, pulping was completed after 100 minutes cooking time. Here Western Cape Bugweed has lowest pulp yield than all other raw material. Pulping yield of Bugweed was comparable to that *E.grandis*. The best pulp yield and the required cooking time for all the raw material was found after application of 16% AA and after 100 minutes cooking time and followed by 15% AA after 130 minutes cooking. Increase in AA charge caused a decrease in pulping time.

Table 4.4: Screened pulp yields (%) of KZN Bugweed from micro bomb digestion against time using different AA additions.

	Screened pulp yield (%)		
Cooking Time (minutes)	AA (%)	AA (%)	AA (%)
	14	15	16
50	13.44	14.42	10.55
100	25.44	49.60	55.32
130	37.68	51.77	49.83
160	49.19	53.34	50.03

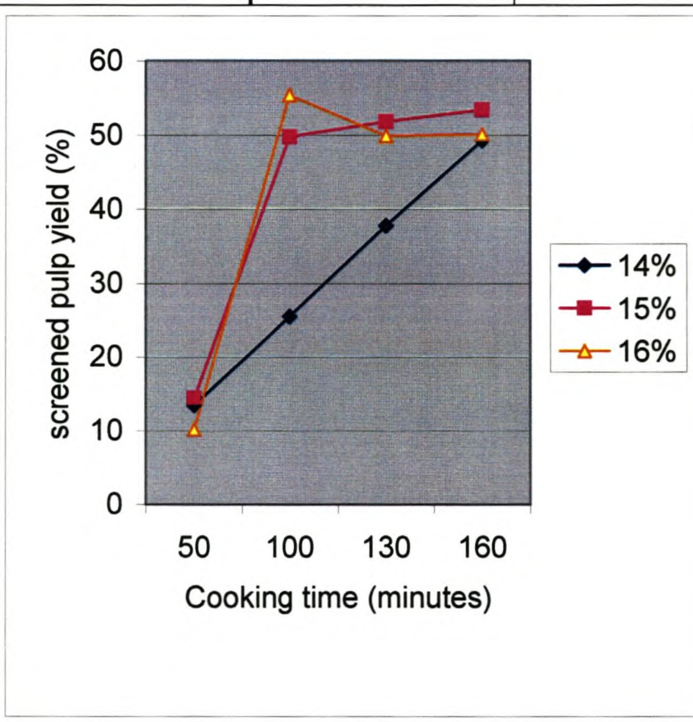

Figure 9: Screened pulp yield (%) of KZN Bugweed from micro bomb digestion against time using different AA additions.

Table 4.5: Screened pulp yield (%) of W.Cape Bugweed from micro bomb digestion against time using different AA additions

	Screened pulp yield (%)		
Cooking Time (minutes)	AA (%)	AA (%)	AA (%)
	14	15	16
50	12.09	14.41	13.22
100	34.75	48.81	50.30
130	46.06	50.62	50.51
160	47.53	50.20	48.78

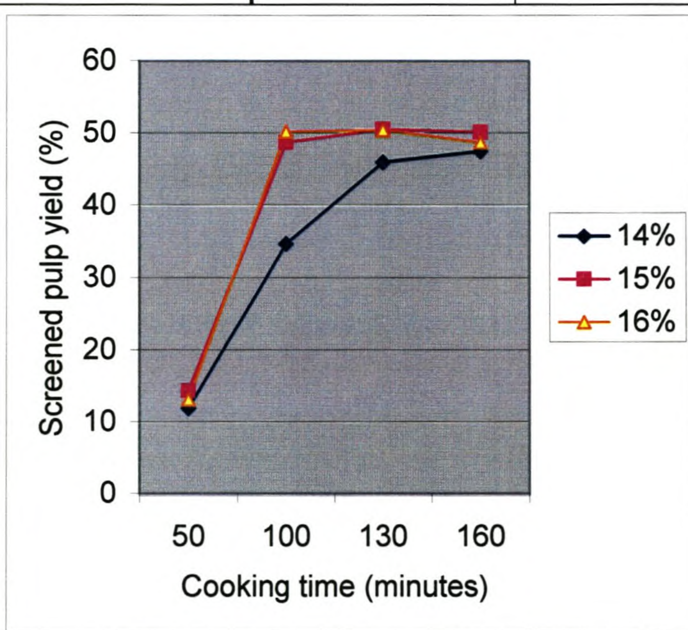

Figure 10: Screened pulp yield (%) of W.Cape Bugweed from micro bomb digestion against time using different AA additions

Table 4.6: Screened pulp yield (%) of Lowveld Bugweed from micro bomb digestion against time using different AA additions.

	Screened pulp yield (%)		
Cooking Time (minutes)	AA (%)	AA (%)	AA (%)
	14	15	16
50	16.22	13.65	13.12
100	37.20	47.90	54.89
130	42.55	50.63	52.13
160	47.30	52.25	54.87

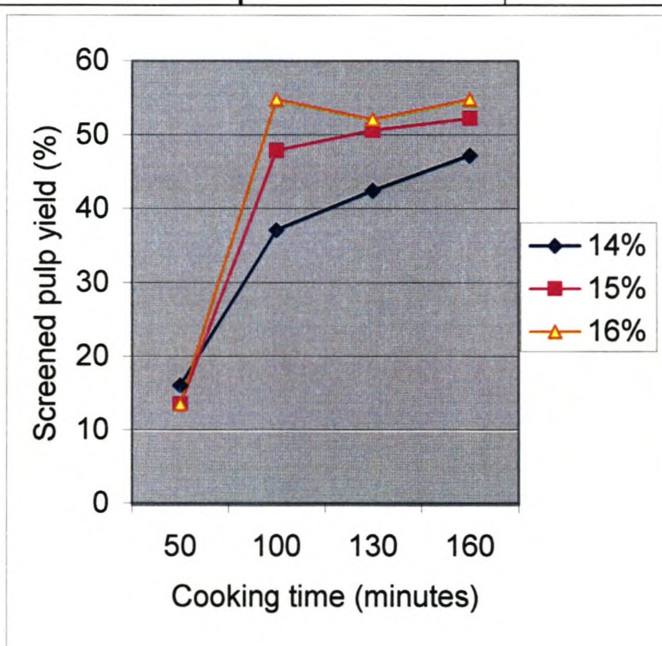

Figure 11: Screened pulp yield (%) of Lowveld Bugweed from micro bomb digestion against time using different AA additions.

Table 4.7: Screened pulp yield (%) of Highveld Bugweed from micro bomb digestion against time using different AA additions.

Cooking Time (minutes)	Screened pulp yield (%)		
	AA (%)	AA (%)	AA (%)
	14	15	16
50	16.23	15.78	14.24
100	38.50	49.18	52.17
130	45.14	46.46	50.7
160	54.61	45.14	51.26

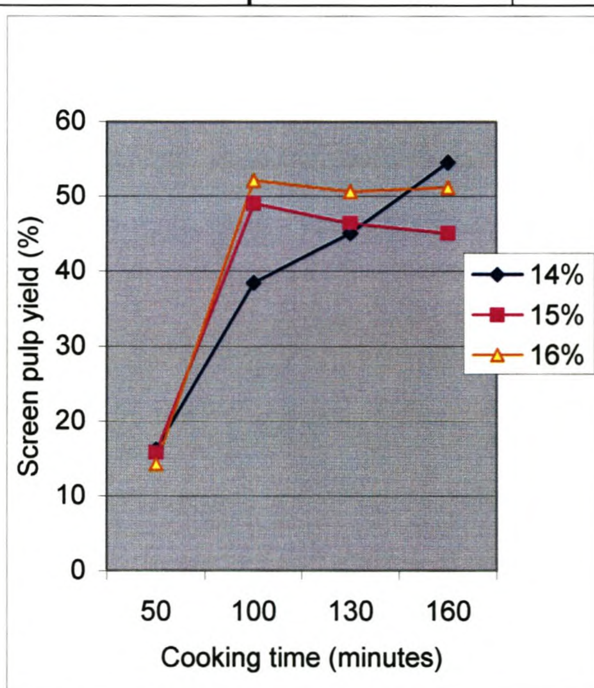

Figure 12: Screened pulp yield (%) of Highveld Bugweed from micro bomb digestion against time using different AA additions.

Table 4.8: Screened pulp yield (%) of E.Cape Bugweed from micro bomb digestion against time using different AA additions.

	Screened pulp yield (%)		
Cooking Time (minutes)	AA (%)	AA (%)	AA (%)
	14	15	16
50	8.79	11.90	16.55
100	22.96	53.05	56.28
130	39.51	51.77	55.41
160	50.71	51.83	54.81

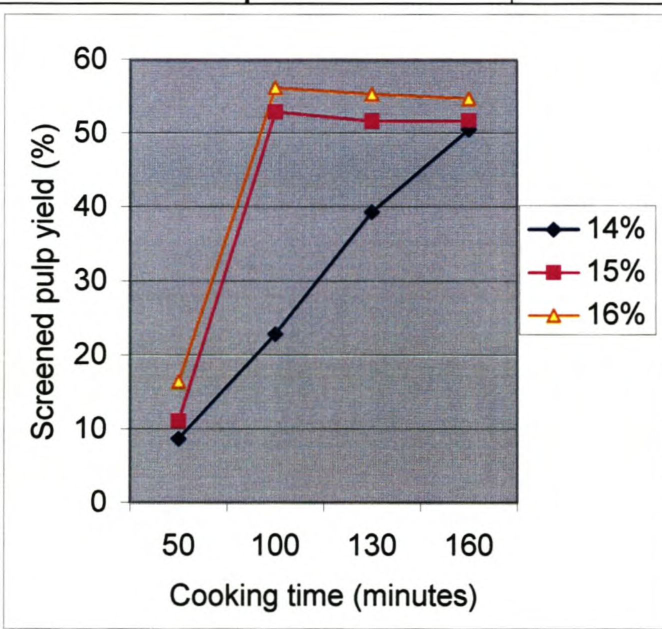

Figure 13: Screened pulp yield (%) of E.Cape Bugweed from micro bomb digestion against time using different AA additions.

Table 4.9: Screened pulp yield (%) of *E.grandis* from micro bomb digestion against time using different AA additions.

	Screened pulp yield (%)		
Cooking Time (minutes)	AA (%)	AA (%)	AA (%)
	14	15	16
50	13.35	16.65	17.24
100	35.50	47.90	54.33
130	52.85	55.09	48.93
160	54.30	54.71	53.87

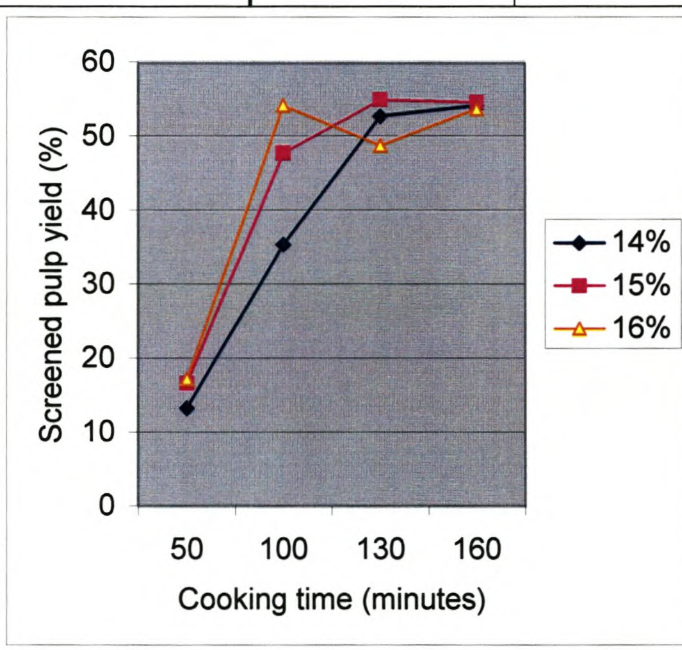

Figure 14: Screened pulp yield (%) of *E.grandis* from micro bomb digestion against time using different AA additions.

4.4.2 Shive content

Figures 15-17 show that the shive content was reduced when the higher alkali additions were made. It is clear that the longer pulping time had a beneficial effect on shive reduction. It also appeared that the Highveld Bugweed material generally produced the highest shive contents. This is not only true when 14% AA and after 130 minutes cook, the Lowveld Bugweed had highest shive content. This may be due to the fact that the Bugweed from Highveld had thicker cell walls (see Table 4.2 page 28) hence it was difficult to separate the fibres. *E.grandis* produced pulp with the lowest shive content probably related to its lower lignin content (Table 4.3 page 33).

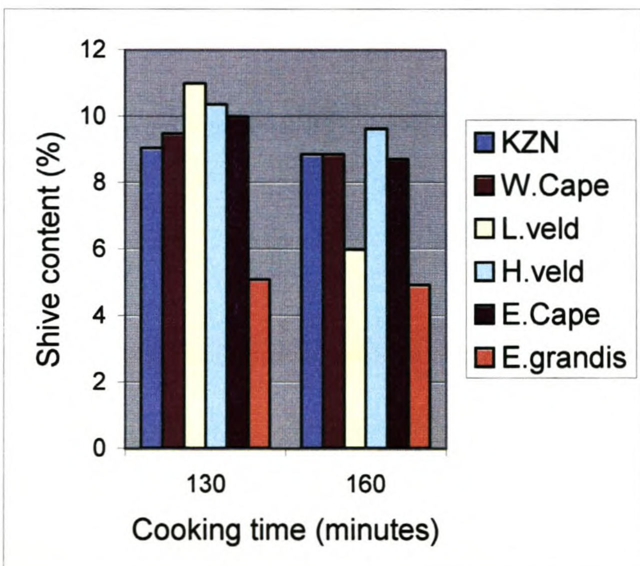

Figure 15: Shive content after screening pulp of 14% AA.

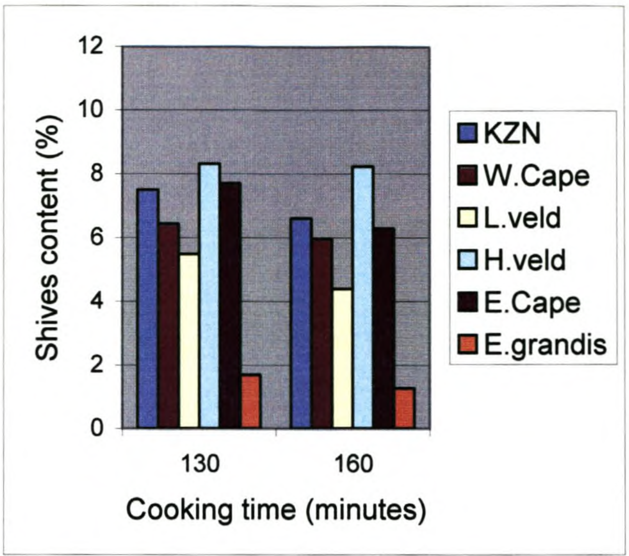

Figure 16: Shive content after screening pulp of 15% AA.

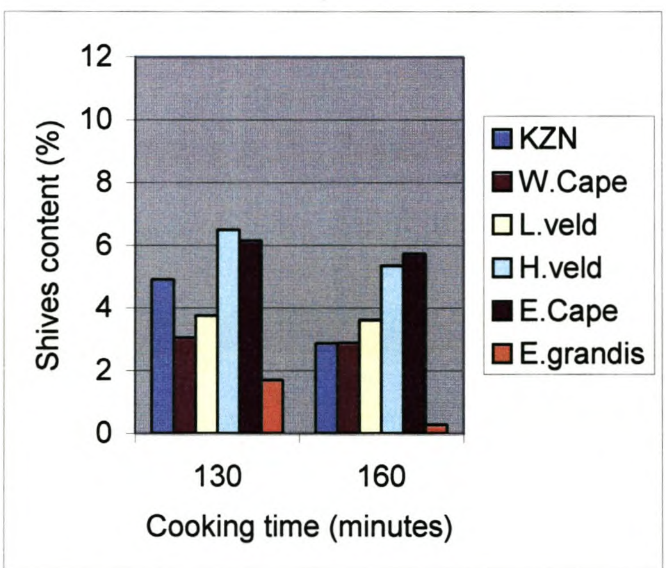

Figure 17: Shive content after screening pulp of 16% AA.

4.4.3 Alkali consumption

Residual alkali in black liquor is expressed as percentage of the initial charge. It is noticeable that the percentage of residual alkali increased with an increased alkali charge in the cooking liquor.

Bugweed from the Highveld region consumed more active alkali than other raw materials. This may be explained by the fact that Bugweed chips from the Highveld region recorded the highest density (see Table 4.1 page 27) and lignin (see Table 4.3 page 33) content as compared to the other materials.

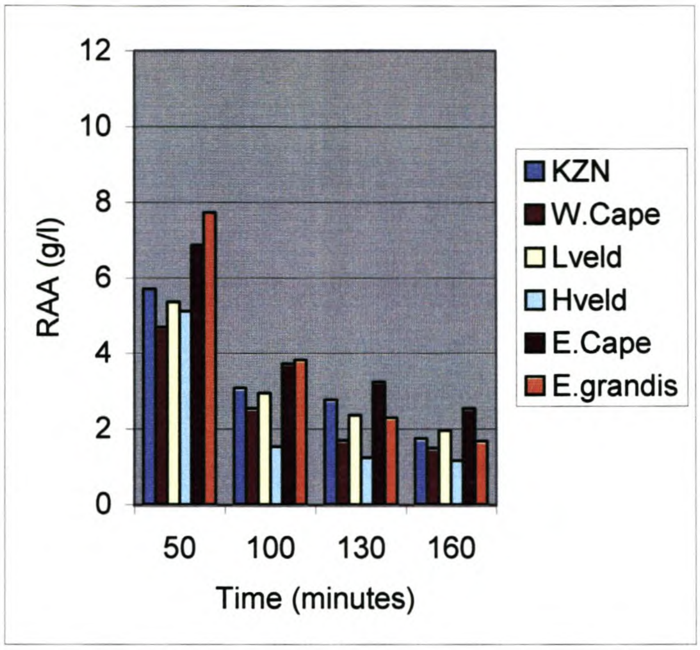

Figure 18: Relationship between percentage residual active alkali (RAA) and cooking time with 14% AA charge.

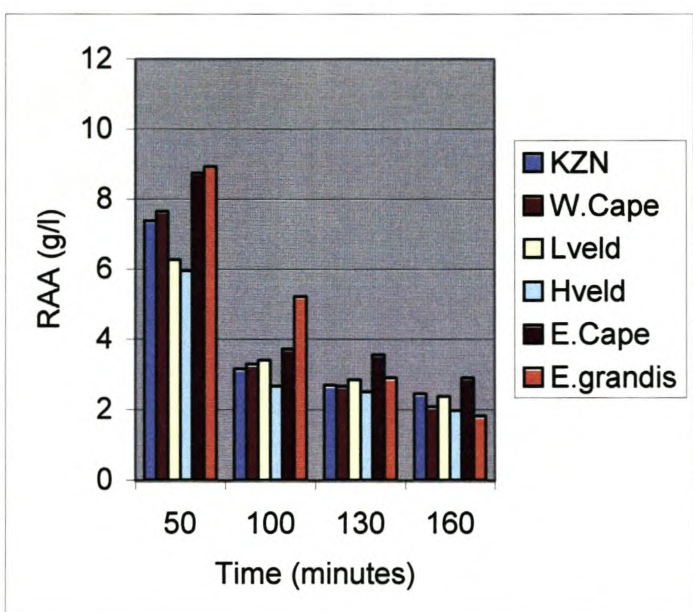

Figure 19: Relationship between percentage of RAA and cooking time with 15% AA charge.

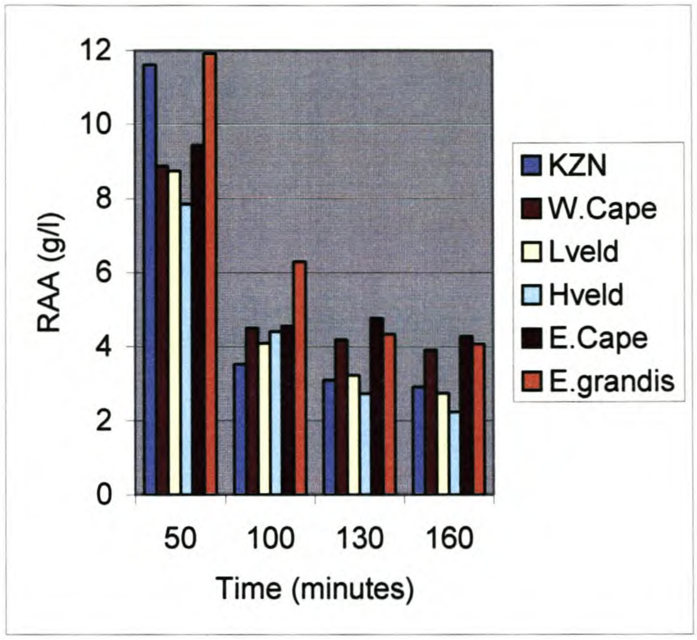

Figure 20: Relationship between percentage RAA and cooking time with 16 % AA charge.

4.4.4 Lampen mill pulp evaluation

The unbeaten handsheet strength properties of all Bugweed pulp samples and the control are given in Table 4.10. The Lampen mill pulp evaluation results (pulp beaten at 30000) revs are shown in Table 4.11 (other results of pulp evaluation are shown in Appendix A). The selection of the Bugweed material with the best and the lowest overall strength development was done according a 1-5 rating points system (where 1 is worst and 5 is best property). Table 4.11 and Table 4.13 show total points obtained from rating system of unrefined and refined pulp. Table 4.14 shows the average of the combined points of refined and unrefined pulp. Accordingly, the Highveld Bugweed and Western Cape Bugweed produced the best strength properties with value a rating of 4.17 (see Table 4.14 page 48) of refined and unrefined pulp whilst the KwaZulu Natal Bugweed produced the lowest handsheet strength values with a rating of 1.83 (see Tables 4.13 page 48). The results for the full Lampen mill beating cycle using the best and lowest rated Bugweed fibre are shown in Figures 21-23. The results clearly indicate that the tear strength for the Bugweed reached its maximum level at 20000 revs, whereas *E.grandis* still had not reached its full potential at the end of the beating cycle. Also it was apparent that the tear strength for Bugweed was lower both in the unbeaten and beaten state. This difference in tear strength most likely can be attributed to the shorter fibre length of the Bugweed fibre, as well as its larger cell lumen diameter, which would make the fibre more flexible and less resistant to tear. Possible also it has something to do with the ball-milling type of beating action of the Lampen mill, which would lower the stiffness of fibres with a large cell lumen, and simultaneously not produce sufficient cell wall fibrillation to achieve good fibre bonding. It has been reported in literature[32] that the Lampen mill beating action deteriorates pulp strength faster than other laboratory beaters and this is probably more relevant for fibres with a higher flexibility such as Bugweed. Figure 21 clearly demonstrates the superior breaking length of the two Bugweeds pulps at a 20000 revs beating cycle. It also appears that *E.grandis* requires more beating input to reach its full breaking length potential, which in turn would mean a higher demand in beating energy.

The burst index results are presented in Figure 23. Both the Highveld and KwaZulu Natal Bugweeds reach their full burst index potential at 20000 revs, whilst *E.grandis* fibres had not reached its full beating potential at the end of the beating cycle. The results presented in Figure 21-23 also clearly show that the Highveld Bugweed developed better sheet strength properties. SEM micrographs (see Figures 24-26) clearly show the large difference in fibre dimensions between the Bugweed and the *E.grandis* fibres. Compared to *Eucalyptus* fibre, which was sharp pointed and slender, the Bugweed fibre was much broader. It is clearly seen that the Bugweed fibre with its large lumen diameter collapsed readily and thus resulted in a large fibre surface bonding or contact area. As the results of this, it is possible to observe the cell walls of underlying fibres at the areas of intersection, as shown in Figure 26.

Table 4.10: Handsheet strength properties of unbeaten Bugweed pulp digested for 130 minutes with a 15% alkali charge, compared to *E.grandis*.

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Wetness °SR	12	16	13	16	15	14
Grammage g/m^2	74.29	72.9	72.17	73.23	73.89	76.02
Burst Index $kPa.m^2 / g$	0.42	0.81	0.47	0.62	0.62	0.82
Tear Index $mN.m^2 /g$	2.16	3.39	2.57	2.79	2.68	3.51
Breaking length km	2.24	3.89	2.24	2.95	2.76	2.95

Table 4.11: Rating points of unrefined pulp (1 point represents the poorest strength and 5 points represent the best strength

Property	KZN	W.Cape	L.Veld	H.Veld	E.Cape
Burst	1	5	2	4	4
Tear	1	5	2	4	3
Breaking length	2	5	2	4	3
Total points	4	15	6	12	10

Table 4.12 Handsheet strength properties of Bugweed pulp beaten to 30000 revolutions with Lampen mill cooked with 15% alkali charge for 130 minutes, compared to *E.grandis*.

Material	Solanum mauritianum					E.grandis
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Wetness °SR	34	44	33	44	38	38
Grammage g/m^2	68.65	72.85	68.59	67.11	73.89	74.14
Burst Index $kPa.m^2 / g$	6.97	8.26	5.54	6.60	5.64	10.24
Tear Index $mN.m^2 /g$	5.18	4.95	5.49	5.83	5.61	10.74
Breaking length km	12.50	14.73	13.35	14.85	13.27	15.37

Table 4.13: Rating points of refined pulp (1 point represents the poorest strength and 5 points represent the best strength

Property	KZN	W.Cape	L.Veld	H.Veld	E.Cape
Burst	4	5	1	3	2
Tear	2	1	3	5	4
Breaking length	1	4	3	5	2
Total points	7	10	7	13	8

Table 4.14: Average rating points for unrefined and refined pulp samples

	KZN	W.Cape	Lveld	Hveld	E.Cape
Burst	2.5	5	1.5	3.5	3
Tear	1.5	3	2.5	4.5	3.5
Breaking length	1.5	4.5	2.5	4.5	2.5
Total average	1.83	4.17	2.17	4.17	3.0

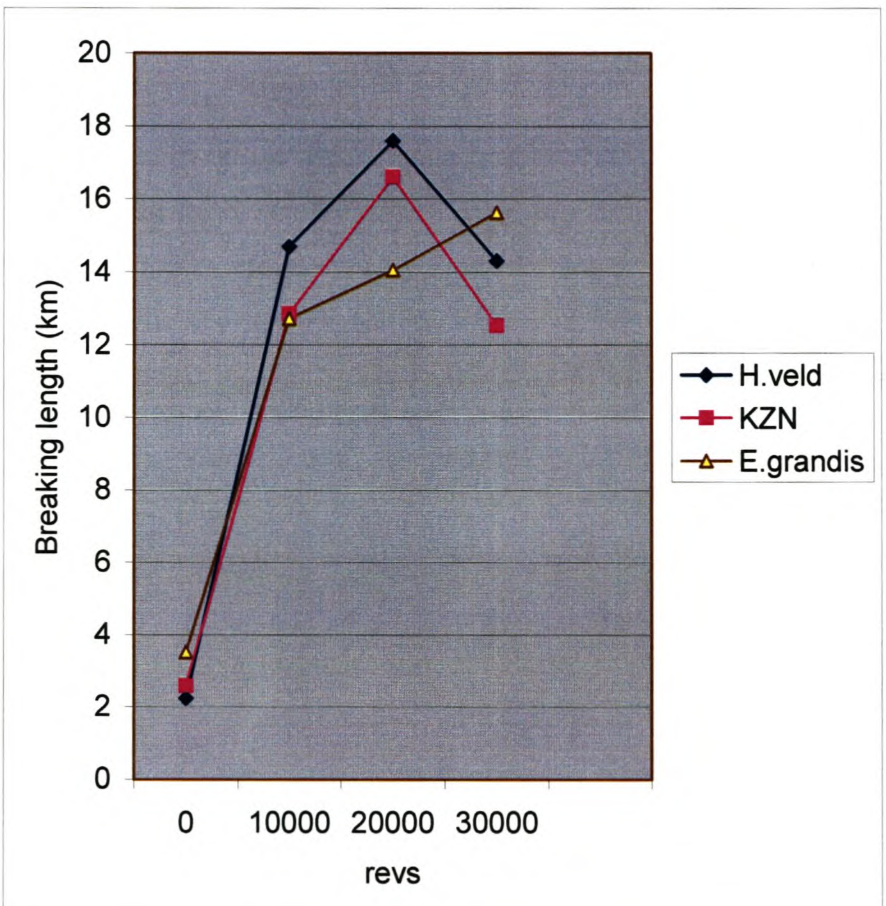

Figure 21: Breaking length of *E.grandis*, Highveld and KZN Bugweed against total number of revs.

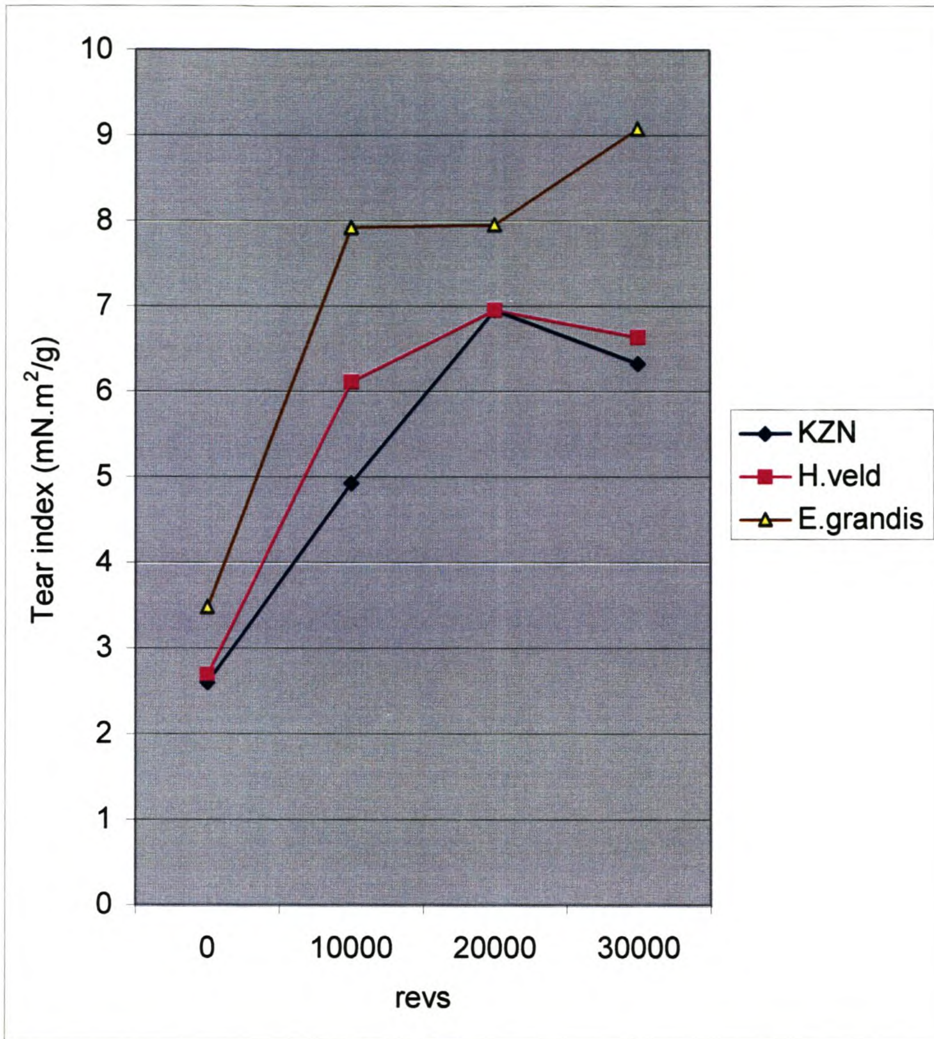

Figure 22: Tear index of *E.grandis* and Bugweed from Highveld (H.veld) and KZN against total number of revs.

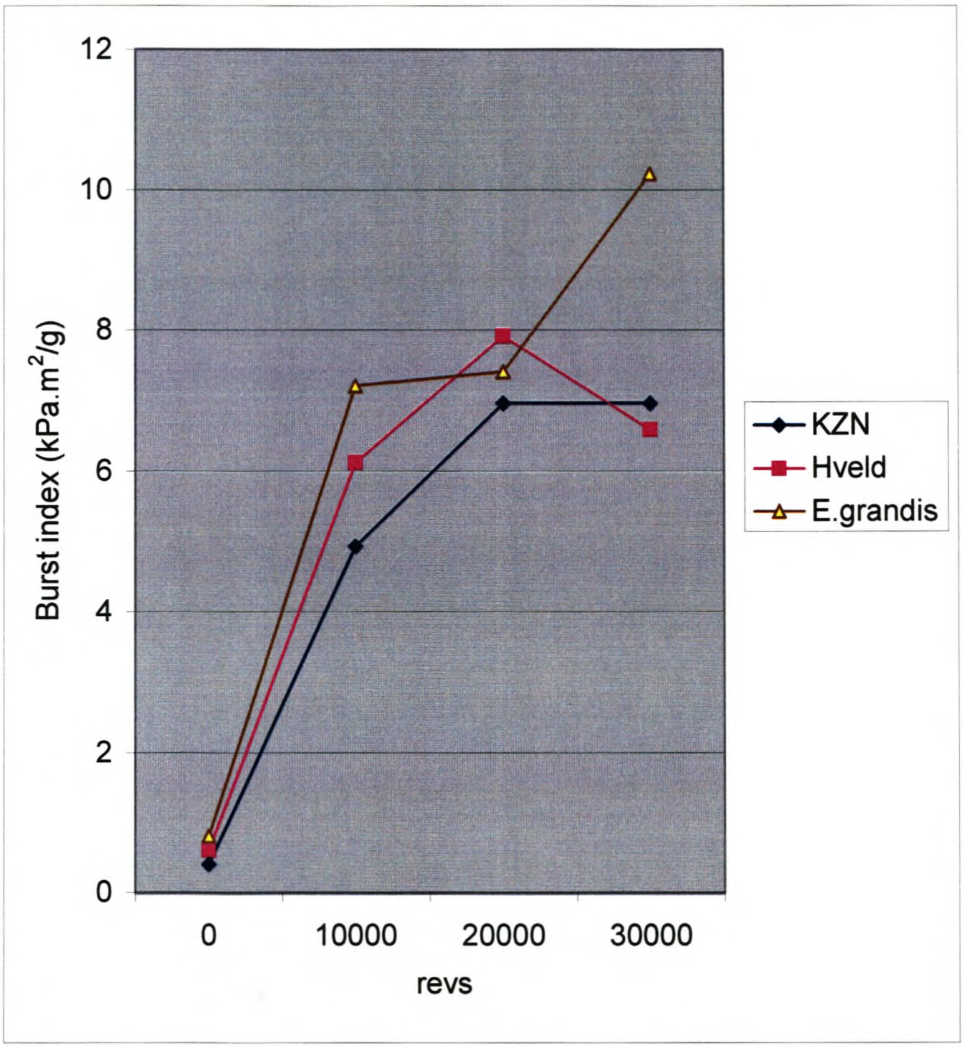

Figure 23: Burst index of *E.grandis* and Bugweed from Highveld and KZN against total number of revs.

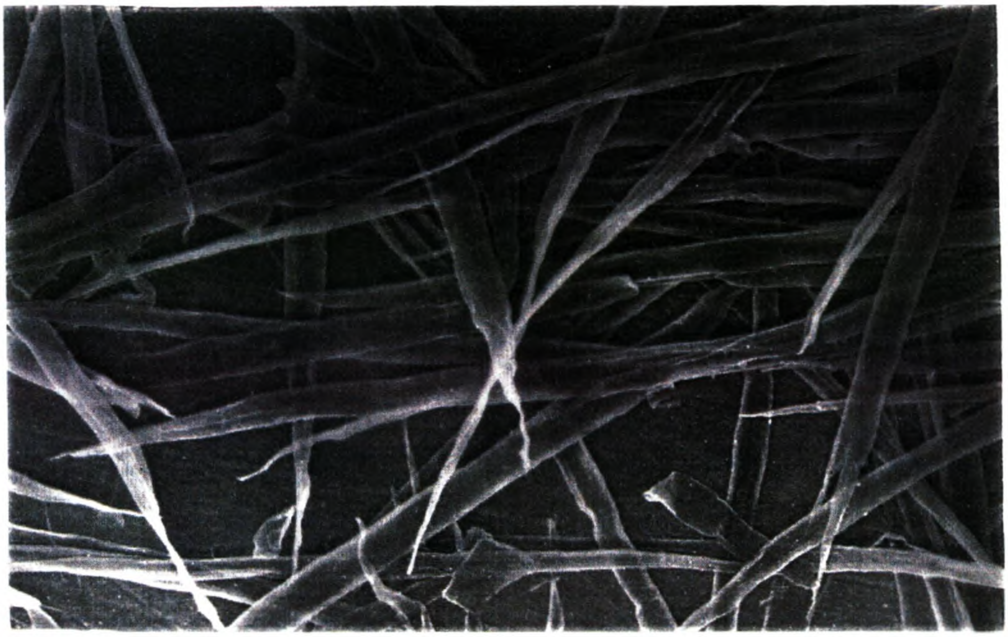

Figure 24: Fibres of unrefined Bugweed

Figure 25: Fibres of unrefined *E.grandis.*

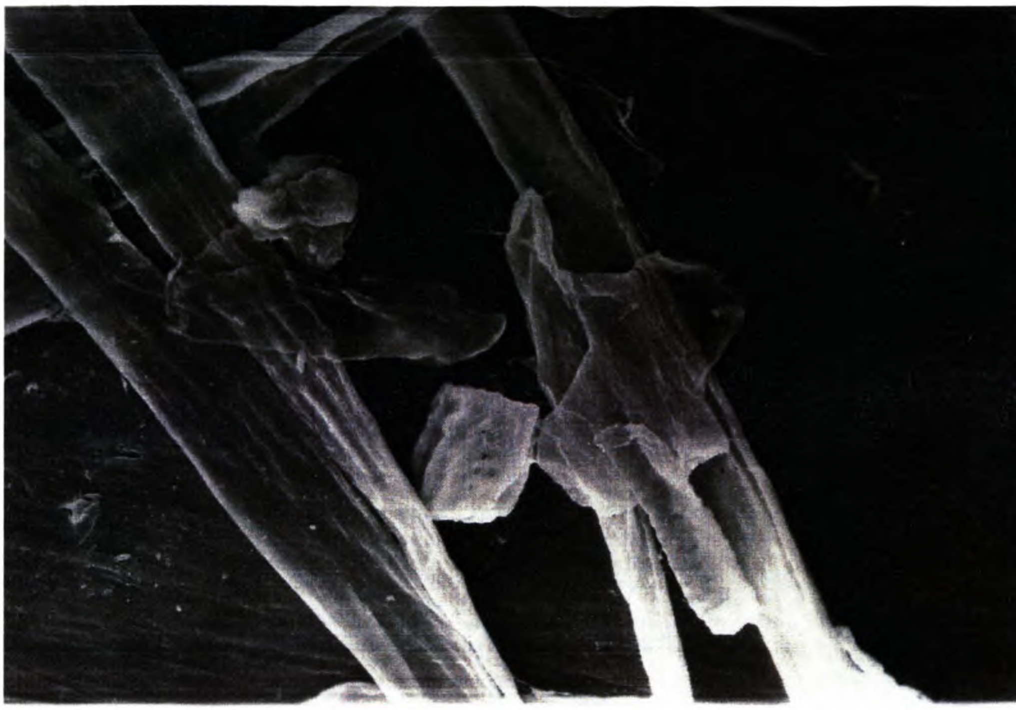

Figure 26: Scanning electron micrograph showing how thin walled Bugweed fibres are (such that you can see the underlying fibre over the top one). Large contact areas between fibres are visible.

4.5 Soda AQ and Kraft Macro pulping

Highveld Bugweed which revealed the best fibre bonding to fibre bonding strength property during micro-scale pulping, was selected to test and to compare its pulp quality under laboratory-scale macro pulping conditions. Both Soda AQ and Kraft macro pulping were used and compared.

4.5.1 Soda AQ Macro pulping

The pulping results for Soda AQ macro pulping are summarised in Table 4.15. Kappa number of Bugweed was higher than that of *E.grandis* whilst the yield and RAA of Bugweed was lower as compared to *E.grandis*. This may be attributed to the fact that Highveld Bugweed had a higher lignin content as compared to *E.grandis*. So Bugweed consumed more alkali but still had a higher amount of residual lignin after digesting.

Table 4.15: Pulping results for Soda-AQ macro pulping.

Raw material	Kappa number	Screened yield (%)	Shives (%)	Total yield [%]	RAA (g/l)
H.Veld Bugweed	25.1	40.15	1.64	41.79	5.67
E.grandis	18.6	48.77	3.3	52.07	9.87

Screened yield of *E.*grandis was higher than that of Bugweed from Highveld. Trials of cooks conducted with micro bombs using Soda AQ produced higher percentages of screened pulp yields as compared to the yields of Soda AQ maco pulping. This may have been attributed to a temperature drop inside the micro bombs, as the heating oil itself was not enclosed.

The noticeable higher burst and tear strength (in Figure 28 and Figure 29 respectively) of the Bugweed fibre obtained from Soda-AQ pulping may be attributed to a clear fibre surface of the Soda-AQ Bugweed fibre which tended to improve the fibre bonding ability. The pulp evaluation results of Soda AQ macro pulping appear in Figures 27-30. Figure 27 clearly demonstrates that the Bugweed pulp responds better to beating and thus would require less energy input to reach a certain wetness value. It can also be seen that the initial unrefined wetness of Bugweed pulp was slightly higher than *E.grandis*. All the handsheet strength characteristics were significantly higher for the Bugweed fibre when compared to *E.grandis*. It is clear that the Voith overhead laboratory basalt-lava beater which can process 800g oven-dry fibre at 4 % stock consistency, was more suitable to develop the high strength potential of the Bugweed fibre as compared to the Lampen mill beating method. The tear strength results in Figure 29 clearly demonstrate that the Bugweed fibre with its totally different morphological cell wall dimensions and cell lumen structures, produced high handsheet tear strength values using the right beating equipment.

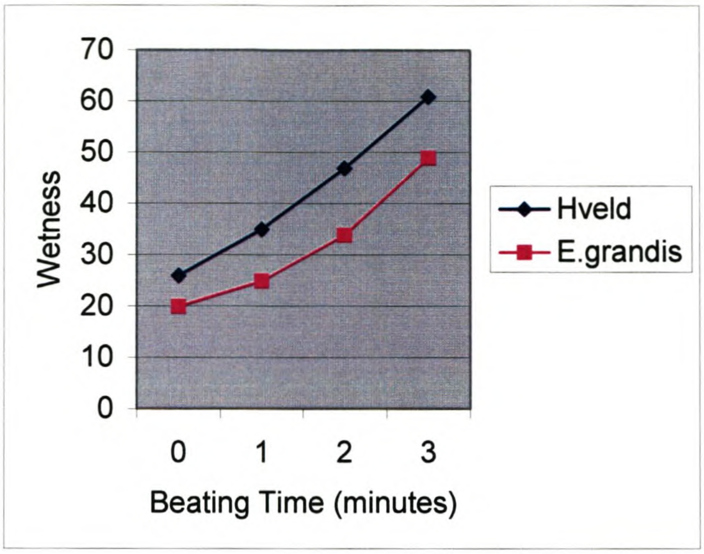

Figure 27: Relationship between beating time and wetness Soda AQ macro pulping

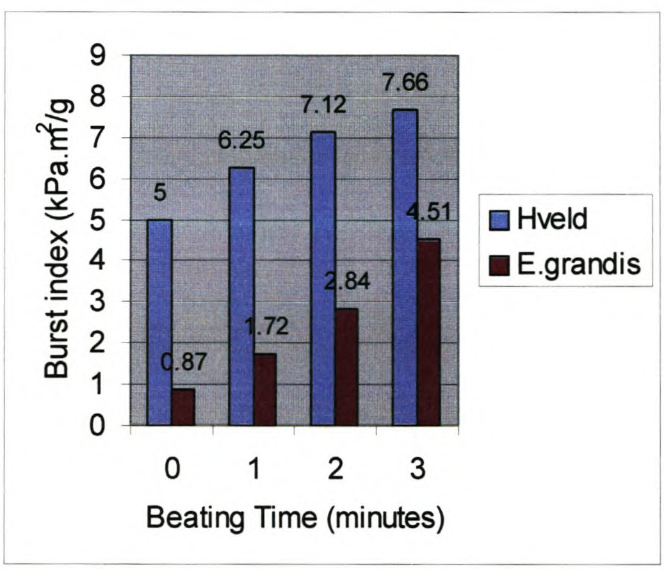

Figure 28: Burst index of Highveld Bugweed compared with *E.grandis* at 38 ^{0}SR Soda AQ macro pulping.

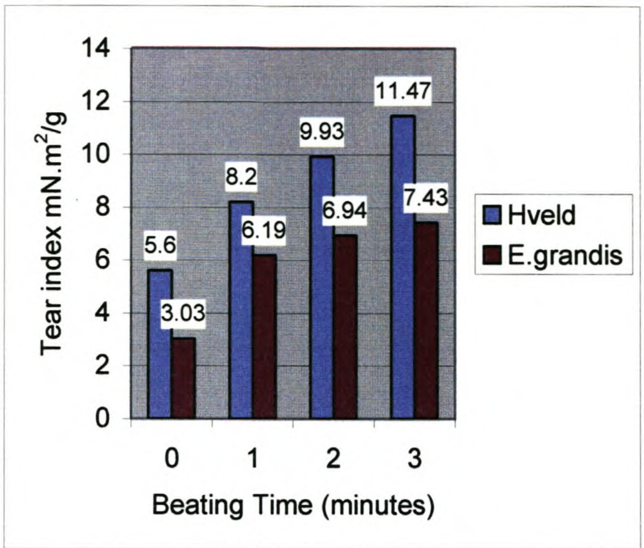

Figure 29: Relationship between tear index and beating time at 38 ^{0}SR Soda AQ macro pulping.

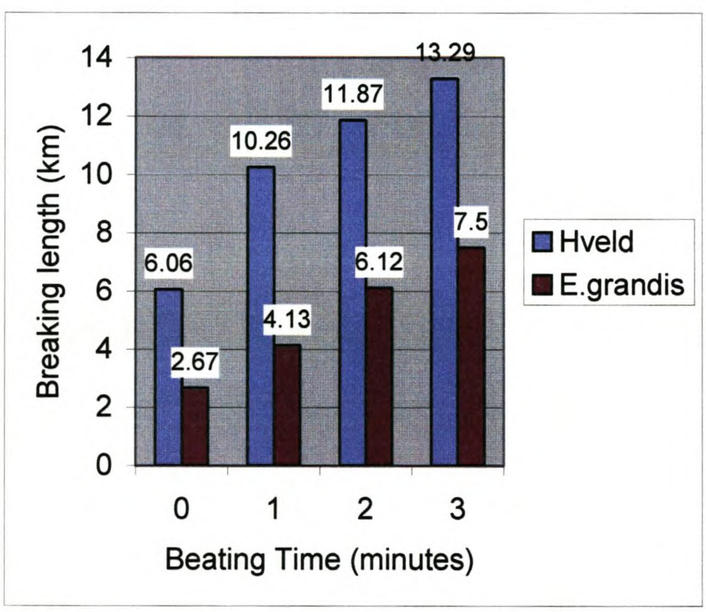

Figure 30: Relationship between breaking length and beating time at 38 ^{0}SR Soda AQ macro pulping.

4.5.2 Kraft Macro pulping

4.5.2.1 Pup strength evaluation

Both the screened pulp yields for the Kraft macro pulping are higher than the corresponding Soda AQ delignification, although the yield differences in case of Bugweed are considerably larger for the two pulping methods. It seems that the sodium sulphide, which forms part of the Kraft cooking liquor, is a better delignification catalyst than the AQ used in Soda pulping. The larger yield difference for the Soda AQ and the Kraft pulping methods in case of Bugweed, probably can be attributed to the thin walled and lower density Bugweed wood chips, which facilitated the swelling and better accessibility of the cell wall material during the delignification in the highly alkaline Kraft cooking liquor

Kraft Bugweed fibre showed beating response which was similar to that of Soda AQ fibre. Bugweed handsheet strength development results were higher than that of *E.*grandis. The results are shown in Figures 31-34. In Table 4.16 it shows clearly that Kappa number of Bugweed was higher than the *E.grandis.* This implies that more chemicals will be needed for bleaching of Bugweed. There was an increase in pulp yield as compared to the pulp yield of Soda AQ pulping. There was reduction in shive content when Kraft pulp was used compared to Soda AQ pulping.

Table 4.16: Pulping results for Kraft macro pulping

Raw material	Kappa no.	Screened yield (%) o.d. wood	Shives (%) o.d wood	Total yield (%)	RAA (g/l)
Highveld Bugweed	22.30	44.53	0.40	44.93	13.57
E.grandis	12.70	49.97	0.07	50.04	19.84

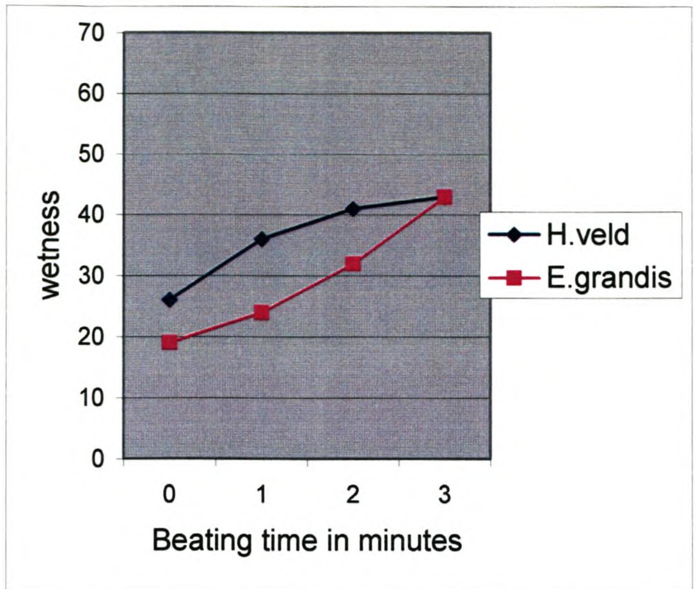

Figure 31: Relationship between wetness ^{0}SR and beating time of Kraft pulp.

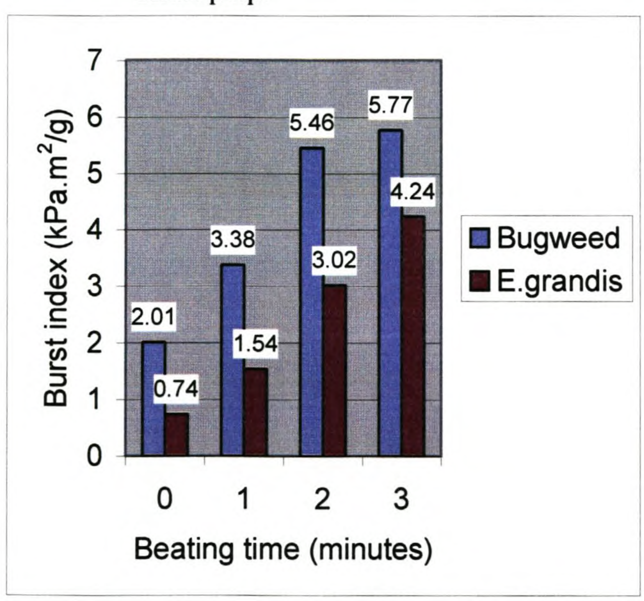

Figure 32: Burst index of *E.grandis* and Highveld Bugweed Kraft pulp

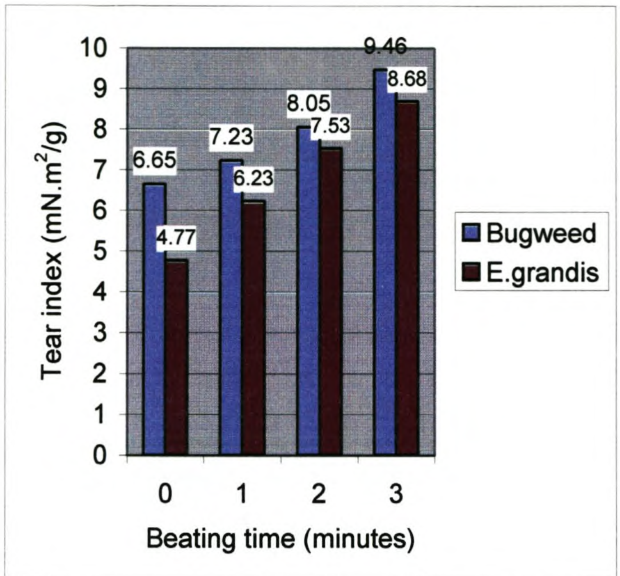

Figure 33: Tear index of Highveld Bugweed and *E.grandis* Kraft pulp.

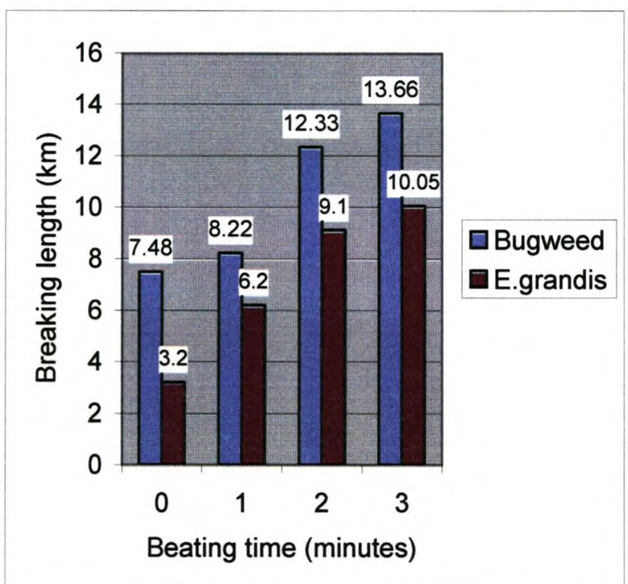

Figure 34: Breaking length of *E.grandis* and Highveld Bugweed Kraft pulp.

4.6 Handsheet evaluation of machine made paper

All paper strength tests were done in the machine direction. Table 4.18 shows strength of unrefined Bugweed whilst *E.grandis* is beaten for 30 seconds. Table 4.18 shows the results of Bugweed and Table 4.18 shows strength of Bugweed beaten to 38 ^{0}SR. In both cases tear index of Bugweed was inferior to that of *E.grandis*. This can be attributed to the fact that Highveld Bugweed had thicker tracheid cell walls as compared to *E.grandis*. Both breaking length and burst indexes of Bugweed were higher than that of *E.grandis*.

Table 4.17: Handsheet evaluation of Bugweed and *E.grandis* at 38 ^{0}SR.

Species	Burst index (kPa.m^2/g	Tear index (mN.m^2/g)	Breaking length (km)
Bugweed	7.67	9.16	19.53
E.grandis	6.11	11.46	15.14

Table 4.18: Handsheet evaluation of Bugweed and *E.grandis* at 25 ^{0}SR.

Species	Burst index (kPa.m^2/g	Tear index (mN.m^2/g)	Breaking length (km)
Bugweed	3.58	10.56	12.34
E.grandis	2.88	10.66	10.11

CHAPTER 5: Conclusions

1. All the Bugweeds from the different regions had a lower extractive content, but showed a considerably higher lignin content as compared to *E.grandis*.
2. All the Bugweeds from different regions had lower densities and shorter fibre length than *E.grandis*. Highveld Bugweed had the highest density and longest fibre length than the Bugweeds from other regions.
3. The micro pulping test results clearly demonstrated that Bugweed could be effectively delignified by Soda AQ pulping using 16% active alkali and 100 minutes total cooking time.
4. For the macro pulping studies, the Kraft and Soda AQ alkaline pulping methods were evaluated. The Kraft pulping method was found to be more suitable for Bugweed pulping as it produced handsheet paper with better yield, tear and breaking length strength values but lower burst index when compared with Soda AQ pulping. Strength development of Kraft pulp was slower than Soda during refining. This might have been due to the fact that there was more swelling in Kraft pulp.
5. The higher lignin content of Bugweed wood was a distinct disadvantage as it resulted in higher pulp Kappa numbers (higher residual lignin content) and consumption of more pulping chemicals during delignification.
6. There was a clear variation in pulping and handsheet strength properties of the Bugweeds from the different regions. This can be related to different anatomical features.
7. The Highveld and the Western Cape Bugweed had the highest handsheet strength values. Altitudes and climatic conditions could be contributing factors. Also the number of vessels may have had an effect in quality of pulp, the more the number of vessels the lower the quality of pulp. The Highveld Bugweed recorded very few vessels, whereas the Lowveld Bugweed and *E.grandis* had numerous vessels.
8. The higher strength development of the Bugweed fibre as compared to *E.grandis* may be attributed to the shorter fibre length of the Bugweed fibre, as well as its larger cell lumen diameter, both which would make the fibre more

flexible and less resistant to tear. SEM observations clearly demonstrated that cell walls of underlying fibres at the areas of intersection were visible.

9. Lampen mill refining damaged strength potential of the Bugweed fibre.
10. The unrefined Bugweed pulp resulted in higher handsheet strength values as compared to *E grandis*. Ultimately this meant that the Bugweed fibre required less refining input to develop a certain paper strength.
11. Unrefined and refined Bugweed fibres produced handsheets with higher breaking length and burst strength as compared to *E.*grandis. However the recorded tear strength values were lower.
12. The sheet strength of the machine made Bugweed paper was significantly higher in comparison to *E.grandis*. Therefore Bugweed fibre can be identified as a short, reinforcing type of furnish for paper manufacture and should contribute to an improvement of sheet strength and paper machine runability.
13. Because of its large cell lumen diameter and its good beating response, the Bugweed fibre would ideally lend itself for the production of highly densified speciality papers, such as silicone based papers.

References

1 NIESCHLAG H.J., EARLE F.R., NELSON G.H. AND PERDUE R.E, Jr., - *A search for new fiber crops. Part II. Analytical Evaluations, continued,* TAPPI 43(12), 993-998, 1960.

2 NIESCHLAG H.J., NELSON G.H., WOLFF I.A. AND PERDUE R.E., Jr., *A search for new fiber crops. Part 111.* TAPPI 43(3), 193-201,March 1960.

3 NELSON G.H., CLARK T.F., WOLFF I.A. AND QUENTIN JONES., - *A search for new fiber crops: Analytical Evaluation.*TAPPI 49(1), 40-48, January 1966.

4 SIMMONDS N.W., - *Evolution of crop plants,* Longman Group Limited, 1976.

5 WALTER S., JUDD C.S.,CAMPBELL E.A., KELLOGG AND STEVENS P.F., - *Plant Systematics: A Phylogenetic Approach,* Sinauer Associates, 1999.

6 LATHROP E.C, NELSON G.H, -*The Chemical Composition of Leaf and Bast fibers,* TAPPI, March 1954, volume 37, number 3.

7 MOORE G, - *Nonwood fibre applications in papermaking* Pira International, 1996

8 PARSAD B., JAKUBSEN, S., AND KOCUREK, M., - *Georgia Kenaf project,* 1995 Pulping Conference, Chicago, USA.

9 KIRBY R.H, - *Papermaking fibres, In vegetable fibre Botany, cultivation and utilization,* Leonard Hill (Books) Ltd, 1963, London

10 Robertson P.E., *The use of non-wood fibres in the manufacture of paper with special reference to South African Grown Sisal fibre*, Master of Science Thesis, Stellenbosch University, 1992.

11 REIHOLD EISHER, - *Fiber characteristics, pulpability and bleachability of switchgrass,* TAPPI Journal, July 199.

12 1995 International Pulp and Paper Directory

13 ALLOTEY A. Unpublished Master of Science Thesis, University of Science and Technology, Kumasi, 1999.

14 RIDDLESTONE S., DESAI P., EVANS M., AND SKYRING A., - *Bioregional fibres: the potential for a sustainable regional paper and textile based on Flax and Hemp,* Carshalton, UK: Bioregional Development Group, 1994

15 LOW I., - *Hemp as a source of fibre,* Silsoe, UK, 23-24 March 1994, vol. 1.

16 BHAT R.V., GUHA S.R.D., KARNIK M.G., AND JASPAL N.S., - *Chemical pulps and writing and printing papers from Sabai grass,* Indian Forester, July 1960.

17 ESWARAN V.V., - *Sugar-sweet newsprint: Tamil Nadu,* World Pap. Vol 219, No.9, September 1994, page 24.

18 MISHRA R.P., MISHRA B.P., KHARE A., MAHESHWARI G.G., BHRGAVA G.G., JOSHI R.C, MANDAL D., SHARMA G., - *Laboratory evaluation of Maharashtra bagasse for development of high brightness pulps under CEHH, CEHD and CED bleaching sequences,* IPPTA Convention Issue 1994, 4-5 March 1994, pp 151-161

19 MARCUS S., - *Colombia more than coffee and cocaine,* Int. Papermaker vol. 58, no.11, November 1995, pp 32-35.

20 ANON, - *Mills for producing pulp, paper, board and processing,* Papel no.45, November 1994, pp71-75.

21 GERISCHER G.F.R. AND WILLEM VAN WYK, - *Micro-pulping wood samples*. Report, University of Stellenbosch, Faculty of Forestry, Stellenbosch, 7600, 1-5, 1988.

22 NAZIR AHMAD AND KARNIK M.G., J. Science of Research (India)2(5):275 (1994).

23 HOCKING A., - *Paper Chain: The story of SAPPI,*Hollard South Africa, 1987, pp53-116.

24 FREELING M. AND WALBOT V., - *The maize handbook,*Springer-Verlag, 1994, pp17-28.

25 STIRTON, C.H, - *Plant invaders,* The Department of Nature and Environmental Conservation of the Cape Provincial Administration, Cape Town, 1978.

26 BENGT KVITZAU AND DARROW K. - *Chemical control of Bugweed and setaria grass in the Eastern Transvaal,* South African Journal, 55-57, September 1983.

27 GERISCHER G.R.F AND VAN WYK, W.J, - *Small-scale Paper production: Handmade paper,* Department of Wood Science, Faculty of Forestry, University of Stellenbosch.

28 GERISCHER G.F.R. AND WILLEM VAN WYK, - *Micro-pulping wood samples.* Report, University of Stellenbosch, Faculty of Forestry, Stellenbosch, 7600, 1-5, 1988.

29 MADDERN N. K. AND FRENCH J, - *The potential application of non-wood fibres in papermaking: an Australian perspective.* Appita Vol. 48

30 VENTER J.S.M, *The manufacture of paper pulp and dissolving pulp from South African sugar-cane bagasse,* Ph.D thesis, Natal University, 1978.

31 SHAFI M., MIAN A.J., AND AKHTARUZZAMAN A.F.M.., - *Neutral Sulphite Anthraquinone Pulping Of Jute Stick.* Bangladesh Journal of forest Science Vol. 23(2) : 86-91, 1994.

32 McKENZIE A.W. - A *comparison of Lampen mill and PFI mill,* Appita 37(1), 53-59, 1983.

33 KEAYS J.L. AND BAGLEY, J.M. - *Digester assembly* for precision pulping studies. TAPPI 53(10), 1935-1940.

34 TAPPI TEST METHODS, T1-T1209, 1992-1993.

35 BROWNING B., L., *The Chemistry of wood,* John Wiley and Sons, 1963.

36 RYPSTRA T., - Personal communication.

37 BURGER R.A., *The effect of chip thickness and extractive content on pulp yield, pulp quality and speed of Soda AQ delignification*, Master of Science Thesis, Stellenbosch University, 1996.

APPENDIX A

Table 4.19 Handsheet strength properties of unbeaten Bugweed pulp digested for 130 minutes with a 14 % alkali charge, compared to *E.grandis*

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Drainage ^{0}SR	15	15	14	17	15	15
Grammage g/m^2	80.38	87.37	78.57	79.05	74.89	75.31
Burst Index kPa.m^2/g	0.43	1.26	0.57	1.04	0.63	0.56
Tear Index mN.m^2/g	2.57	4.25	2.64	3.90	2.51	3.59
Breaking Length km	2.36	5.02	2.88	4.53	3.04	2.72

Table 4.20 Handsheet strength properties of Bugweed beaten pulp to 30000 revolutions with Lampen mill cooked with 14% alkali charge for 130 minutes, compared *E.grandis*.

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Drainage °SR	37	34	33	41	37	41
Grammage g/m^2	74.58	69.57	70.67	73.85	66.88	74.51
Burst Index $kPa.m^2 / g$	5.50	7.18	5.8	5.82	4.61	10.25
Tear Index $mN.m^2 /g$	4.63	5.24	6.03	6.00	5.38	8.58
Breaking length km	13.59	13.39	12.85	14.36	12.38	15.28

Table 4.21 Handsheet strength properties of unbeaten Bugweed pulp digested for 130 minutes with a 14% alkali charge, compared with *E.grandis*.

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Drainage °SR	15	15	14	17	15	15
Grammage g/m^2	80.38	87.37	78.57	79.05	74.89	75.31
Burst Index $kPa.m^2 / g$	0.43	1.26	0.57	1.44	0.63	0.56
Tear Index $mN.m^2 /g$	2.57	4.25	2.64	4.90	2.51	3.59
Breaking length km	2.36	5.02	2.88	5.53	3.04	2.72

Table 4.22 Handsheet strength properties of Bugweed beaten pulp to 30000 revolutions with Lampen mill cooked with 14% alkali charge for 160 minutes, compared *E.grandis*.

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Drainage °SR	38	40	38	42	38	40
Grammage g/m^2	80.26	69.59	67.3	69.67	68.42	74.23
Burst Index $kPa.m^2$ / g	5.67	7.57	5.14	6.92	4.55	8.45
Tear Index $mN.m^2$ /g	5.87	5.10	5.97	5.23	5.50	9.20
Breaking length km	12.49	12.56	13.20	15.36	11.70	14.82

Table 4.23 Handsheet strength properties of unbeaten Bugweed pulp digested for 160 minutes with a 15% alkali charge, compared with *E.grandis*.

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Drainage °SR	15	15	14	16	13	15
Grammage g/m^2	78.03	72.52	71.88	74.35	78.51	73.04
Burst Index $kPa.m^2 / g$	0.43	0.60	0.74	0.74	0.40	0.74
Tear Index $mN.m^2 /g$	2.61	2.65	2.47	2.70	2.65	3.49
Breaking length km	2.58	2.14	2.77	2.24	2.43	3.52

Table 4.24 Handsheet strength properties of Bugweed beaten pulp to 30000 revolutions with Lampen mill cooked with 15% alkali charge for 160 minutes, compared *E.grandis.*

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Drainage °SR	34	45	37	44	38	42
Grammage g/m^2	70.54	64.84	65.57	68.32	73.62	71.19
Burst Index $kPa.m^2$ / g	6.78	8.99	7.99	7.93	5.72	10.56
Tear Index $mN.m^2$ /g	6.34	4.97	5.36	6.65	6.14	9.08
Breaking length km	12.71	13.51	13.94	14.29	12.51	15.62

Table 4.25 Handsheet strength properties of unbeaten Bugweed pulp digested for 130 minutes with a 16% alkali charge, compared with *E.grandis*.

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Drainage °SR	11	14	13	16	10	17
Grammage g/m^2	75.1	75.83	75.06	73	72.42	74.37
Burst Index $kPa.m^2 / g$	0.34	0.45	0.46	0.52	0.61	0.84
Tear Index $mN.m^2 /g$	1.88	2.03	2.88	2.79	2.93	4.57
Breaking length km	2.02	2.57	2.02	2.70	3.04	3.00

Table 4.26 Handsheet strength properties of Bugweed beaten pulp to 30000 revolutions with Lampen mill cooked with 16% alkali charge for 130 minutes, compared *E.grandis*.

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Drainage °SR	33	43	50	56	45	40
Grammage g/m^2	69.3	74.56	75.31	68.46	70.46	72.19
Burst Index $kPa.m^2 / g$	6.88	8.65	6.83	8.18	5.73	9.52
Tear Index $mN.m^2 /g$	6.84	5.68	4.58	5.33	4.68	10.40
Breaking length km	13.34	13.75	11.58	12.43	13.09	16.20

Table 4.27 Handsheet strength properties of unbeaten Bugweed pulp digested for 160 minutes with a 16% alkali charge, compared with *E.grandis*.

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Drainage °SR	13	14	13	15	13	13
Grammage g/m^2	76.29	76.06	83.98	75.2	75.99	70.77
Burst Index $kPa.m^2$ / g	0.20	0.43	0.42	0.41	0.39	0.83
Tear Index $mN.m^2$ /g	1.41	2.82	2.20	2.35	2.04	4.38
Breaking length km	1.6	2.36	2.23	2.33	2.47	2.75

Table 4.28 Handsheet strength properties of Bugweed beaten pulp to 30000 revolutions with Lampen mill cooked with 16% alkali charge for 160 minutes, compared *E.grandis*.

Material	*Solanum mauritianum*					*E.grandis*
Origin	KZN	W.Cape	L.Veld	H.Veld	E.Cape	KZN
Drainage °SR	33	44	40	45	45	38
Grammage g/m^2	71.77	71.5	80.55	72.33	70.32	71.44
Burst Index kPa.m^2 / g	7.15	7.30	8.10	8.65	6.37	9.25
Tear Index mN.m^2 /g	6.59	6.65	5.84	5.32	4.82	10.19
Breaking length km	13.37	13.32	12.55	13.96	13.87	15.67